RAPPAHANNOCK RIVER SLACK WATER DATA REPORT

TEMPERATURE, SALINITY, DISSOLVED OXYGEN

1970 - 1980

T. J. Brooks

Data Report #18

Virginia Institute of Marine Science
School of Marine Science
College of William and Mary
Gloucester Point, Virginia 23062

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ACKNOWLEDGEMENTS

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Over the past ten years, many students and technicians in the Department of Physical Oceanography and Hydraulics have shared in the hard work and the frustrations that accompany bad weather conditions and the problems of boats and instruments. They also have suggested many improvements based on their accumulated field experience. I particularly thank the following persons for their long time contribution to the program by conducting the field work: Messrs. W. Matthews, S. Snyder, K. Worrell, J. Cumbee and S. Fenstermacher. I also thank Ms. Nancy Courtney for the data reduction and Mr. Hugh Brooks for the development of the interfacing program and the selection of the SURFACE II options.

The funding of this project is jointly provided by the Virginia State Water Control Board and the Virginia Institute of Marine Science through the Cooperative State Agencies program.

INTRODUCTION

The slack water survey program, which has been supported by the State Water Control Board and the Virginia Institute of Marine Science under the Cooperative State Agencies program, provides an extended series of temperature, salinity, dissolved oxygen and nutrient measurements along the Rappahannock River. These have been used to:

1) calibrate, verify, and update mathematical models;

2) provide a baseline against which effects of unusual events have been measured;

and could be used to:

3) establish annual and longer period "climatological" trends in response to changing natural phenomena and man-made modifications to the estuary;

4) provide a basis against which fluctuations in biota could be compared.

This report contains station locations, survey schedules, field procedures, sample handling procedures, and data reduction and storage procedures. In addition, 11 years of contoured temperature, salinity, and dissolved oxygen data is presented.

The primary purpose of this report is to provide the data in a format which will be useful to others. Analysis and interpretation of the data is underway and this will be the subject of a later report.

I. SLACK WATER SURVEY PROGRAM

A. Description of the Study Area

The Rappahannock River is located in Virginia as can be seen in Figure 1. The tidal portion of the Rappahannock River extends 172 kilometers from the river mouth in a generally north-west direction to Fredericksburg (Division of Water Resources, 1970). This portion of the river drains an area of 2,613 square kilometers. The 126 kilometers of river above Fredericksburg drain an additional 4,142 square kilometers (Seitz, 1971). The average discharge near Fredericksburg is 47.35 cubic meters per second based on 73 years of record. The discharge has ranged from 0.14 to 3,960 cubic meters per second (USGS, Water Resources Data for Virginia, 1981).

The water surface area of the tidal Rappahannock River is 401.5 square kilometers at mean low water. The mean low water volume is 1.783×10^9 cubic meters. Figure 2 is a plot of the mean tidal range which is 0.36 meters at the mouth and 0.82 meters at Fredericksburg. Figure 3 shows the time difference for high and low water relative to Hampton Roads. The duration of tidal rise and the duration of tidal fall is presented in Figure 4 (Cronin, 1971).

The climate in the study area is classified as humid subtropical. The average annual air temperature in the Rappahannock River basin is $13.4^{\circ}C$. Average monthly air

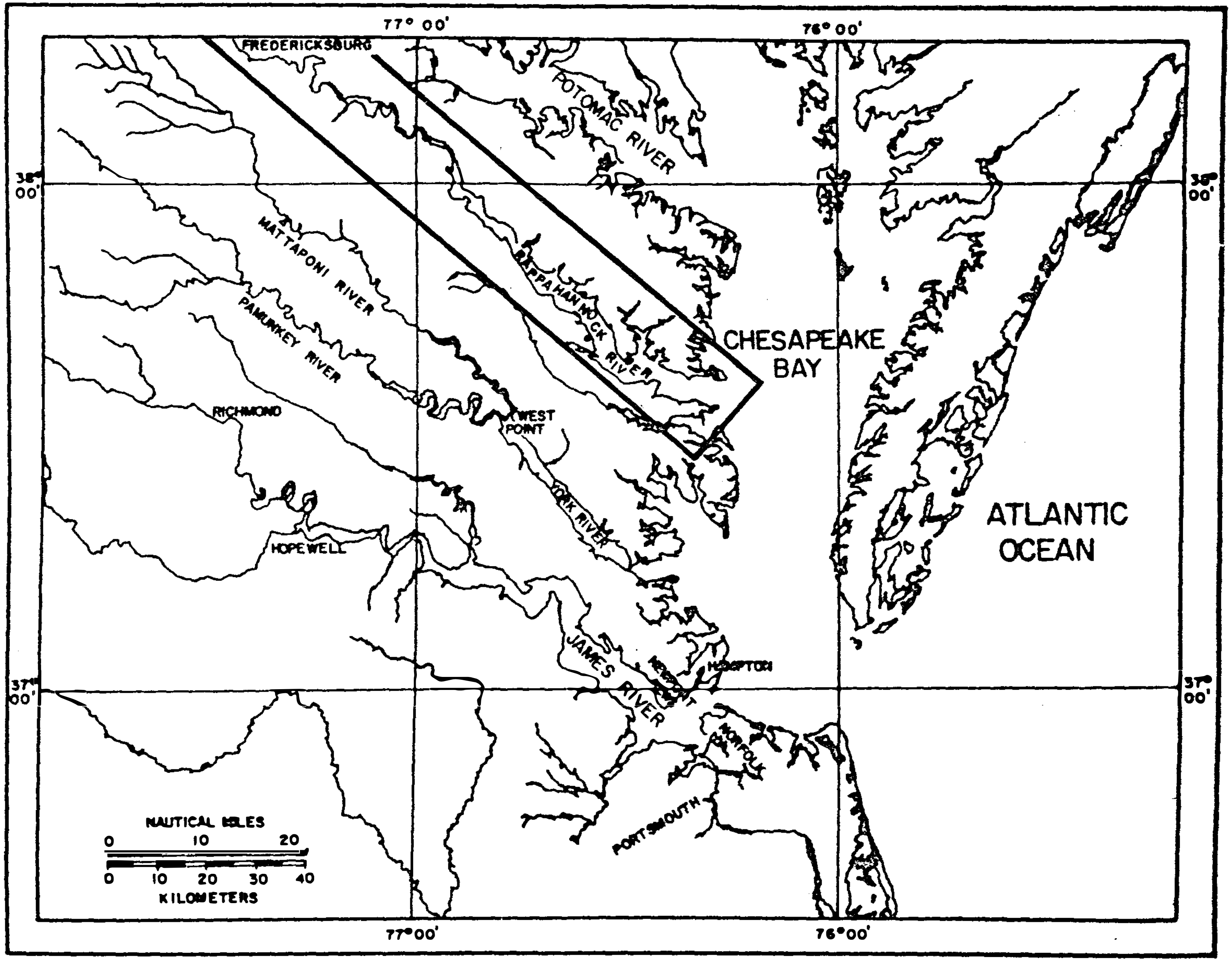


Figure 1. Map Locating the Rappahannock River Within Virginia

FIGURE 2. MEAN TIDAL RANGE

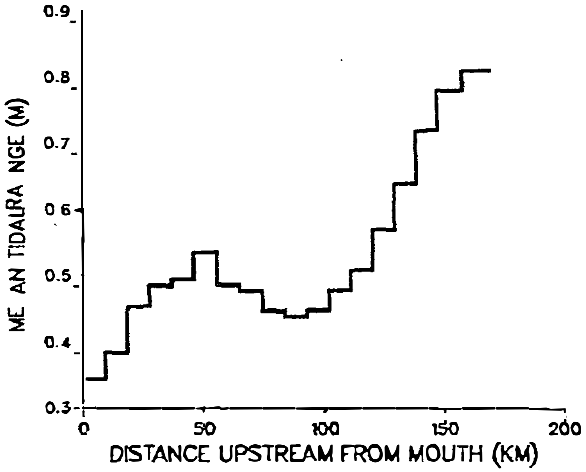


FIGURE 3. TIME DIFFERENCE FOR HIGH AND LOW WATER RELATIVE TO HAMPTON ROADS

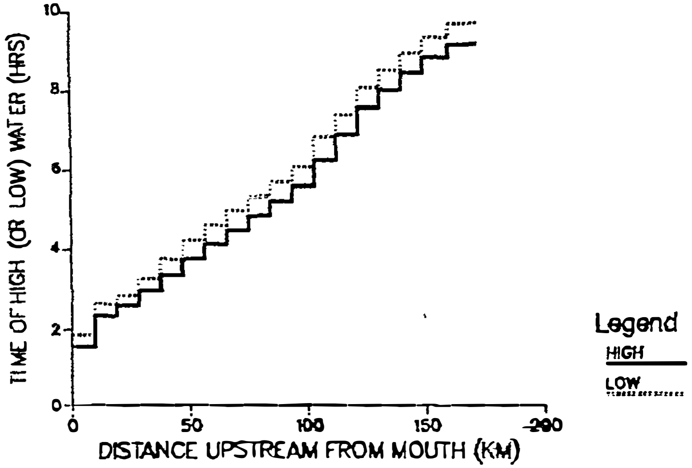
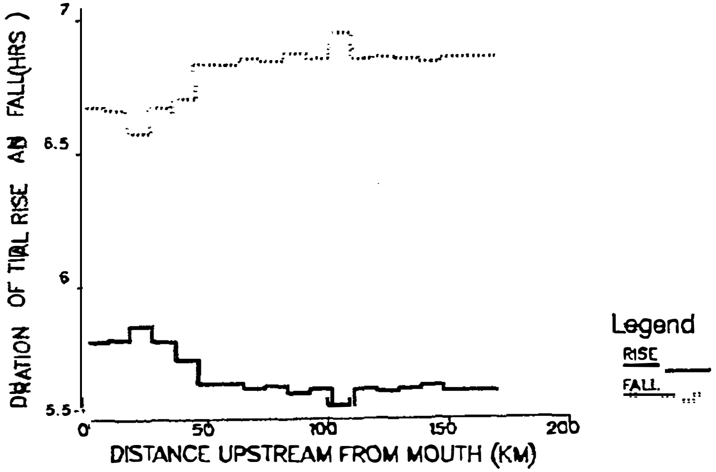


FIGURE 4. DURATION OF TIDAL RISE AND DURATION OF TIDAL FALL



(Cronin, 1971)

temperatures range from 1.9°C in January to 24.9°C in July. The average annual precipitation in the basin is 101.2 centimeters (NOAA, Climatological Data, 1980).

B. Slack Water Survey Criteria

A slack water survey is made by taking water samples at designated locations while following either the high or low water slack wave (slack water before ebb tide or slack water before flood tide respectively) as it progresses upstream from the estuary mouth. Most stations are located near the middle of the navigation channel. Water samples from at least two points in the water column, one near the surface and one near the bottom, are taken at each station. At stations of sufficient depth additional points in the water column may be sampled. (See section C, "Field Procedures", for more detailed information.) The locations of the most frequently sampled stations are shown in Figure 5, where the station designation refers to the distance from the river mouth in kilometers. Table 1 lists each station by its kilometer designation, latitude and longitude, and water depth.

A reasonable time table for collecting the samples is 15-20 minutes at the first station. This estimate includes the time spent getting the equipment organized and situated in the boat. Stations up river average 5 to 10 minutes each.

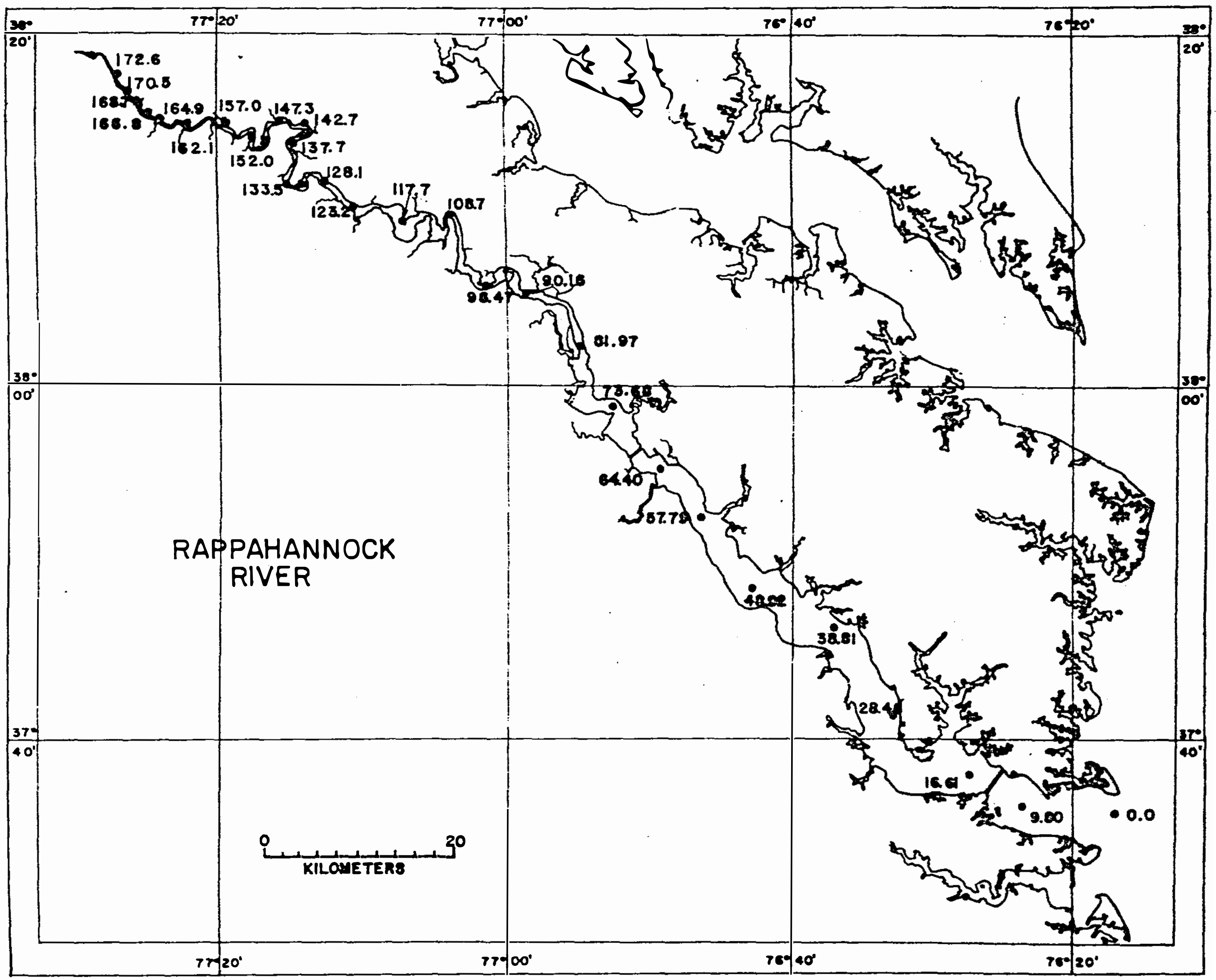


Figure 5. Map of the Rappahannock River Showing the Station Locations

Table 1. Rappahannock River Slack Water Survey Stations

Distance (km)	Latitude (north)	Longitude (west)	Depth (m)
00.00	37-35.8′	76-17.1′	12.9
09.80	37-36.8′	76-23.6′	18.9
16.61	37-38.0′	76-27.8′	22.5
28.48	37-41.2′	76-32.8′	12.0
38.81	37-45.9′	76-37.0′	15.6
48.92	37-48.5′	76-42.8′	07.8
57.79	37-52.5′	76-46.4′	07.5
64.40	37-55.2′	76-49.3′	07.8
73.68	37-58.8′	76-52.7′	05.1
81.97	38-02.1′	76-54.8′	09.6
90.16	38-05.1′	76-58.7′	08.1
98.47	38-05.5′	77-01.3′	15.3
108.7	38-09.7′	77-03.8′	18.0
117.7	38-09.3′	77-07.2′	04.5
123.2	38-09.9′	77-10.4′	04.8
128.1	38-11.7′	77-12.7′	09.3
133.5	38-11.4′	77-15.2′	10.8
137.7	38-13.3′	77-14.8′	05.1
142.7	38-14.8′	77-14.0′	04.8
147.3	38-14.8′	77-16.6′	03.0
152.0	38-13.9′	77-17.6′	02.7
157.0	38-14.7′	77-19.5′	03.6
162.1	38-14.8′	77-22.2′	04.2
164.9	38-14.9′	77-23.8′	03.9
166.8	38-15.4′	77-24.9′	06.9
168.7	38-16.1′	77-25.6′	03.9
170.5	38-16.8′	77-26.2′	04.5
172.6	38-17.6′	77-27.1′	02.1

Every effort is made to complete a slack water survey once it has started. The decision to abort a survey may be made when weather conditions, and more importantly wave conditions, have reached such a point that the slack water time table can not be met. In some cases a few of the stations near the river mouth can be skipped and the survey continued upstream. If half of the river is skipped in order to find more tranquil water conditions the lower portion is rescheduled for no later than the next day. When this is not possible the entire slack water survey is rescheduled.

Surveys usually are conducted monthly, except in the winter, by two-person crews in small outboard boats which are able to keep pace with the slack wave. Winter sampling is generally suspended due to the over-saturation of dissolved oxygen and the low temperatures. The months during which slack water surveys have been conducted are presented in Table 2.

The slack water surveys are scheduled so that the field crews spend the least possible amount of time working during darkness. Usually, the surveys start no earlier than one hour before daylight and are run no later than one hour after sunset. This policy is mainly a safety consideration in an effort to avoid running the boats at top speeds in a limited visibility situation. Since they are the longest, the Rappahannock and James rivers are given first priority as to scheduling dates.

Table 2. Months of Slack Water Surveys (High and Low) for 1970-1980

Rappahannock River

	1970		1971		1972		1973		1974		1975		1976		1977		1978		1979		1980	
	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L
January						X	X															
February			X	X			X															
March			X	X		X	X			X												
April			X	X	X	X			ⓧ			△X		ⓧ		△X				△X		
May			X	X	X	X	ⓧ		ⓧ			△X	ⓧ			△X		△X				
June				X						ⓧ			ⓧ			△X	△X			△X	X	
July			X				ⓧ	ⓧ	ⓧ	ⓧ					△X	△X		△X	X	X		△X
August	X		X				ⓧ	ⓧ		ⓧ					△X	△X	△X	△X				△X
September				X		X		X		ⓧ			△X	△X	△X						△X	
October	X	X		X		X		X		△X	△X	△X	△X	△X			△X	△X	ⓧ	△X		△X
November		X	X			X				△X		X	△X	△X		△X		△X	X			
December	X	X			X				△X													

X : Temperature, Salinity, D.O.

ⓧ : T, S, D.O., and B.O.D.

△X : T, S, D.O., B.O.D., Chlorophyll and Nutrients

H : High water slack; slack before ebb

L : Low water slack; slack before flood

Prior to 1978 when daily precipitation was greater than 0.3 of an inch the survey was postponed for a period of usually three days. This sometimes caused problems as far as scheduling the surveys, especially when the month was drawing to a close. Since 1978 the policy has been changed and the surveys are no longer postponed due to rain.

Figures 6a-k show daily fresh water discharge and the dates of each slack water survey. The fresh water discharge is measured near Fredericksburg (USGS, Water Resources Data for Virginia, Water Years 1970-1981) and represents approximately 61.3% of the drainage area of the Rappahannock River basin (Seitz, 1971). Figures 7a-k show average predicted tide heights and the dates of each slack water survey. The tidal data is from Sewells Point and is presented as the average of the high tide heights for each day and the average of the low tide heights for each day (NOAA, Tide Tables 1970-1980).

C. Field Procedures

Several types of samples are collected during each survey. Temperature readings, salinity, and dissolved oxygen samples are taken during each slack water survey. Conductivity readings and biochemical oxygen demand samples are often taken. Since 1974, nutrient concentrations and chlorophyll 'a' have been measured at least a few times each year, as indicated in Table 2.

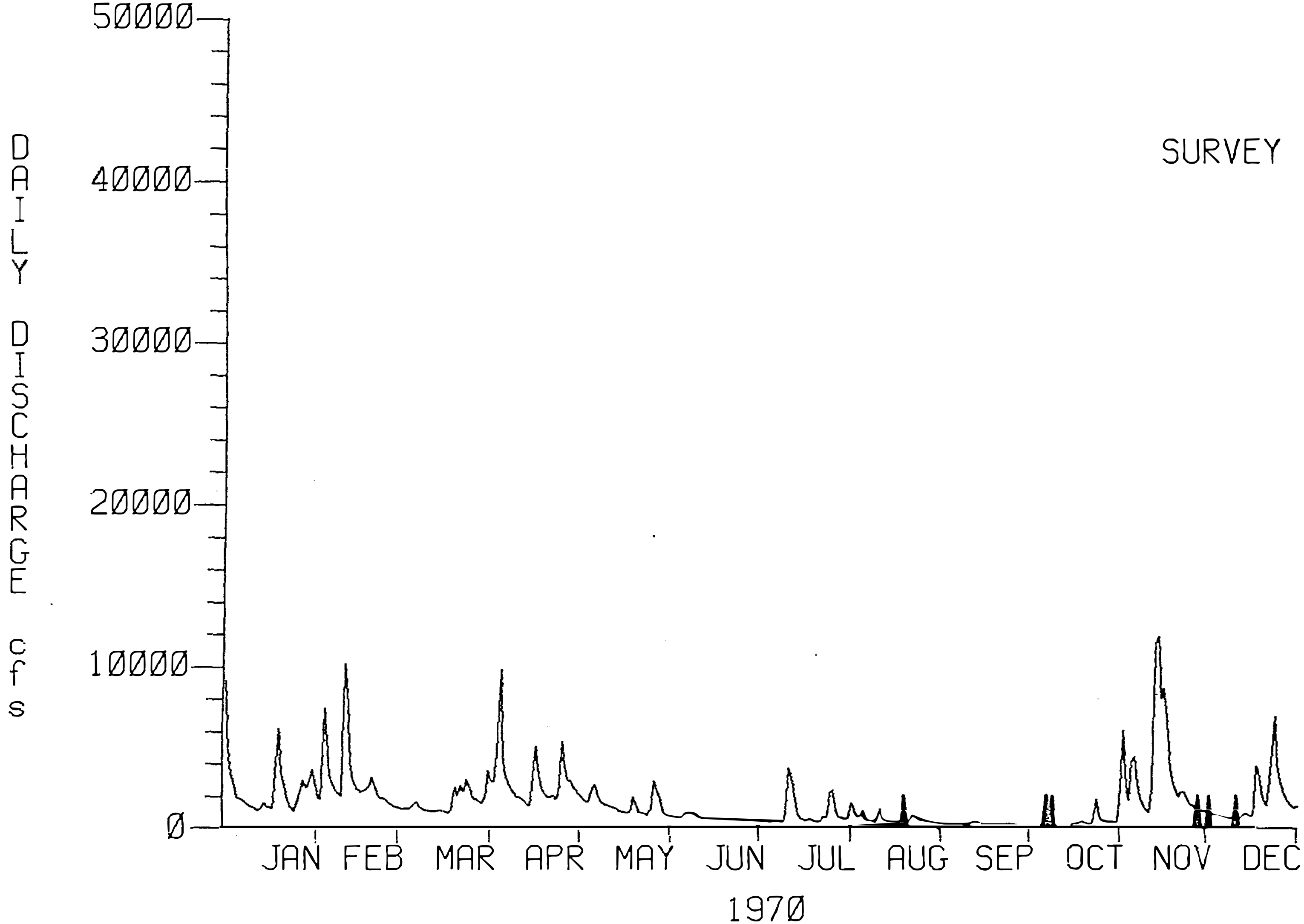


Figure 6a. Fresh Water Discharge and Slack Water Survey Dates, 1970

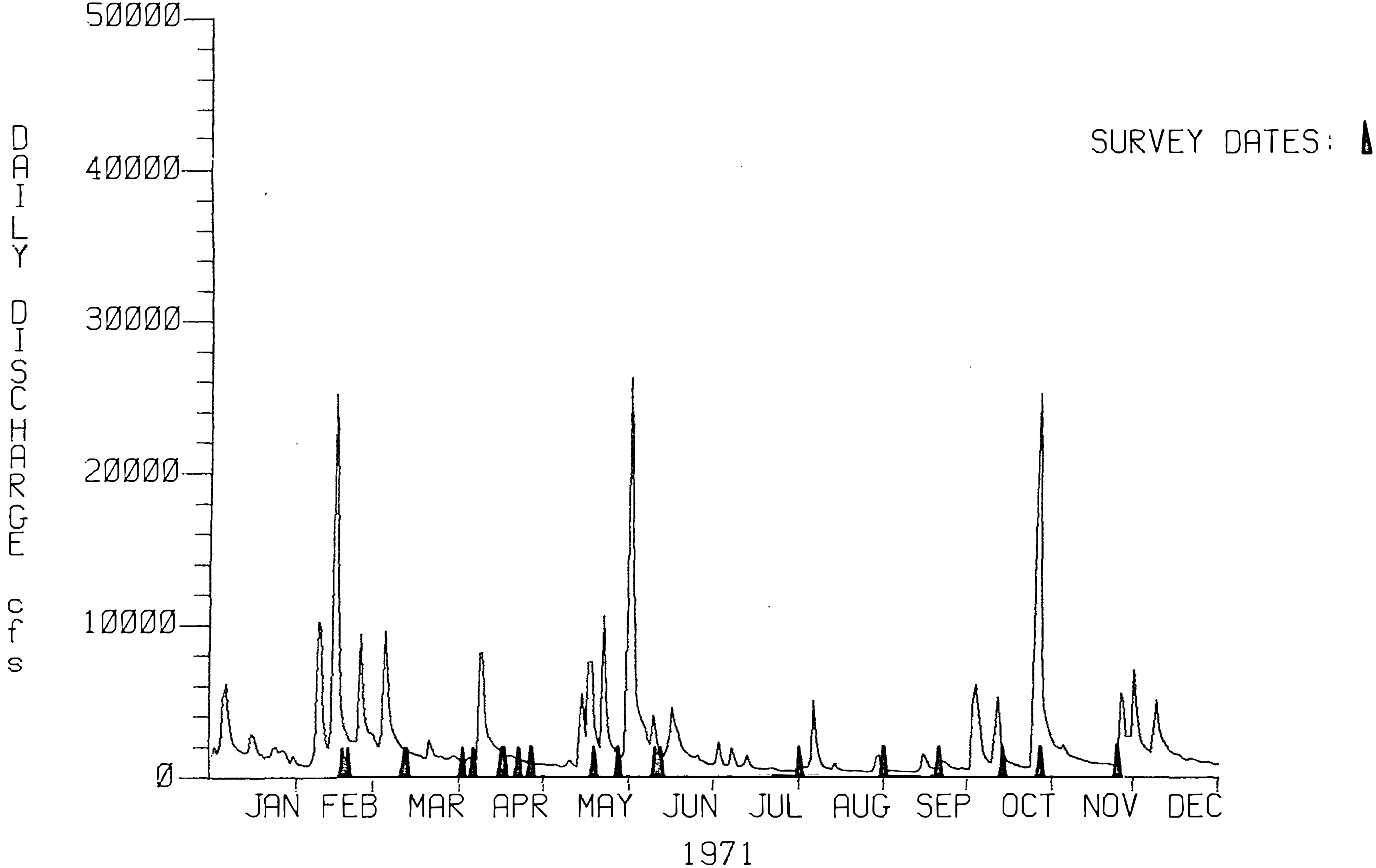


Figure 6b. Fresh Water Discharge and Slack Water Survey Dates, 1971

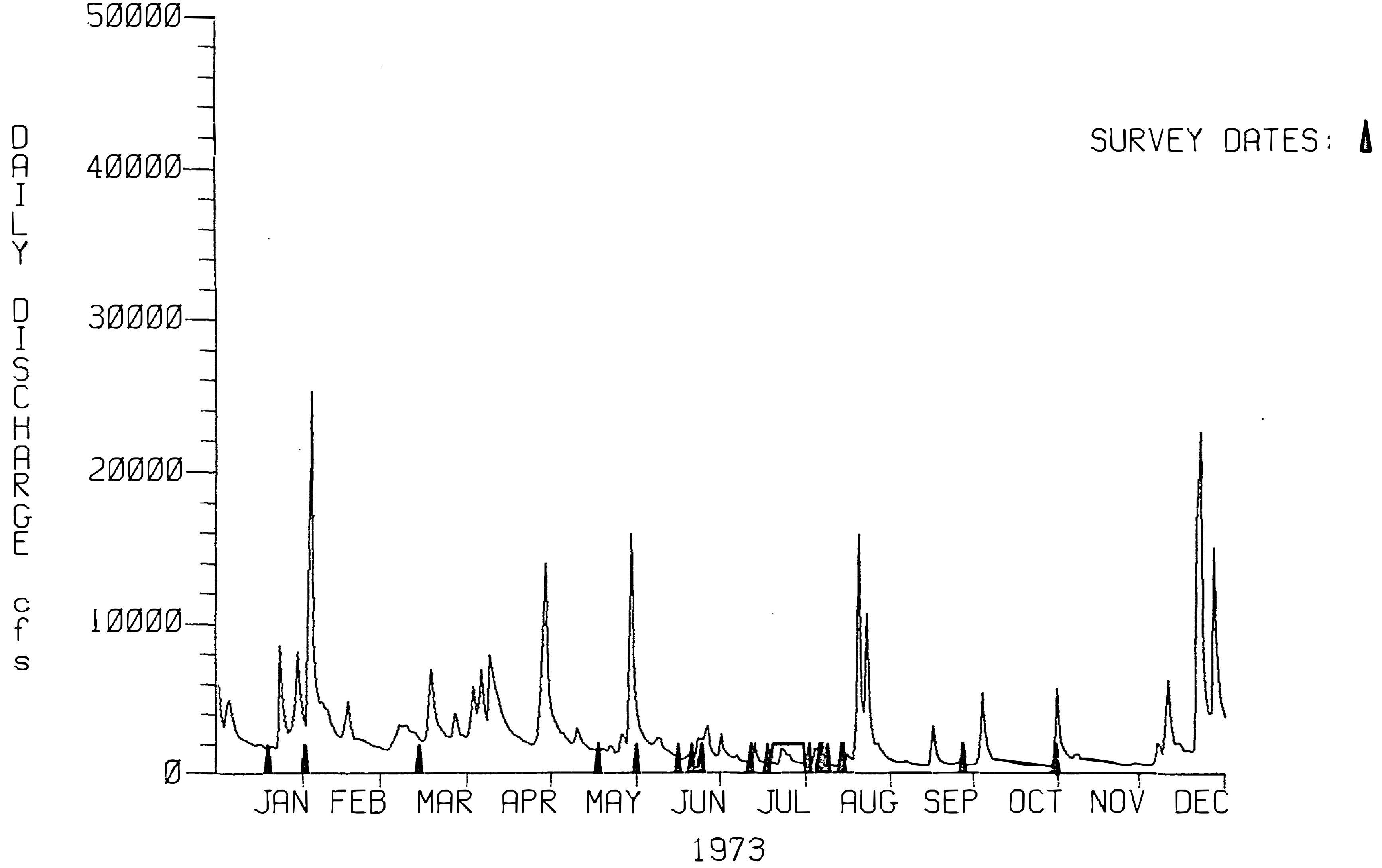


Figure 6d. Fresh Water Discharge and Slack Water Survey Dates, 1973

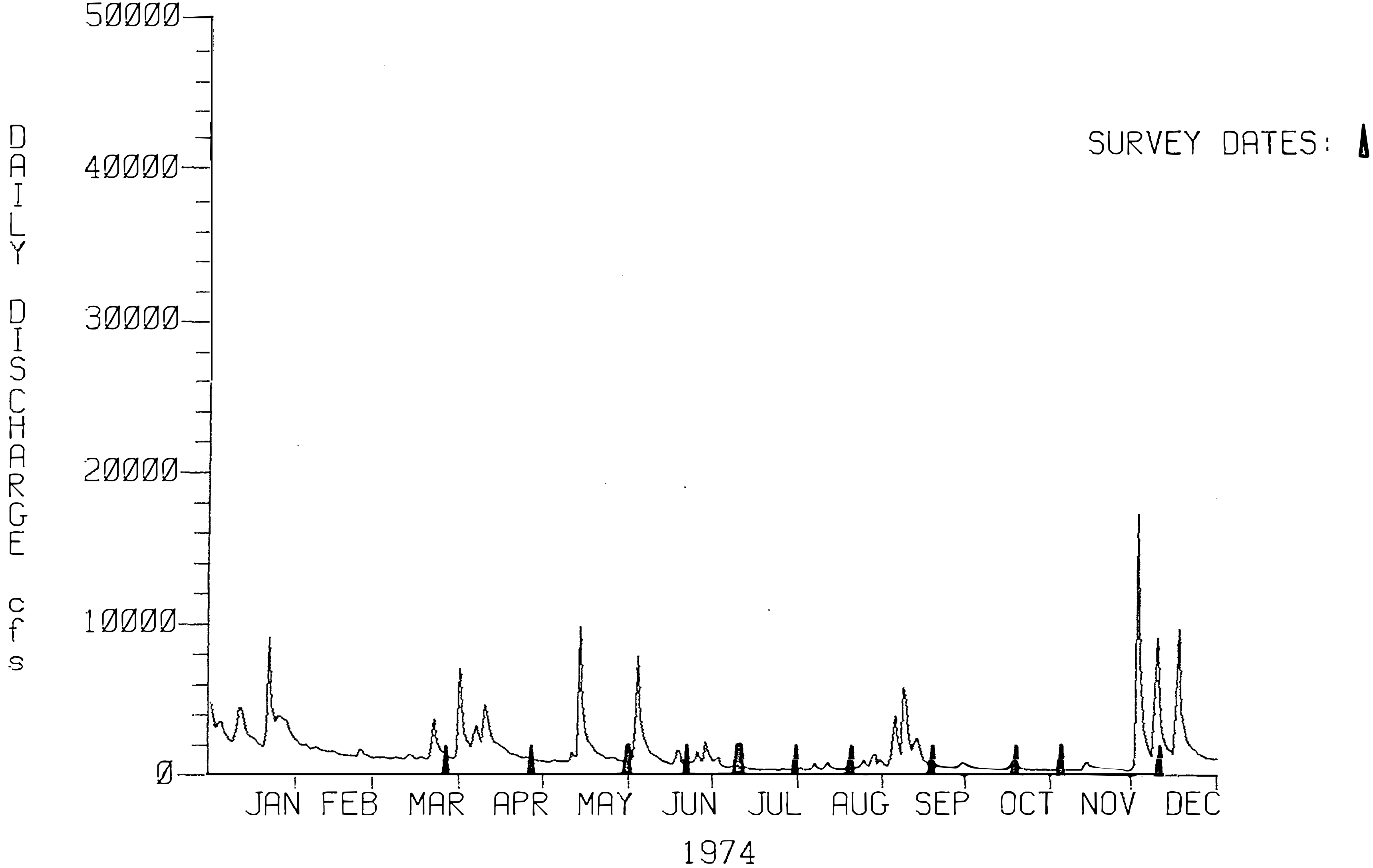


Figure 6e. Fresh Water Discharge and Slack Water Survey Dates, 1974

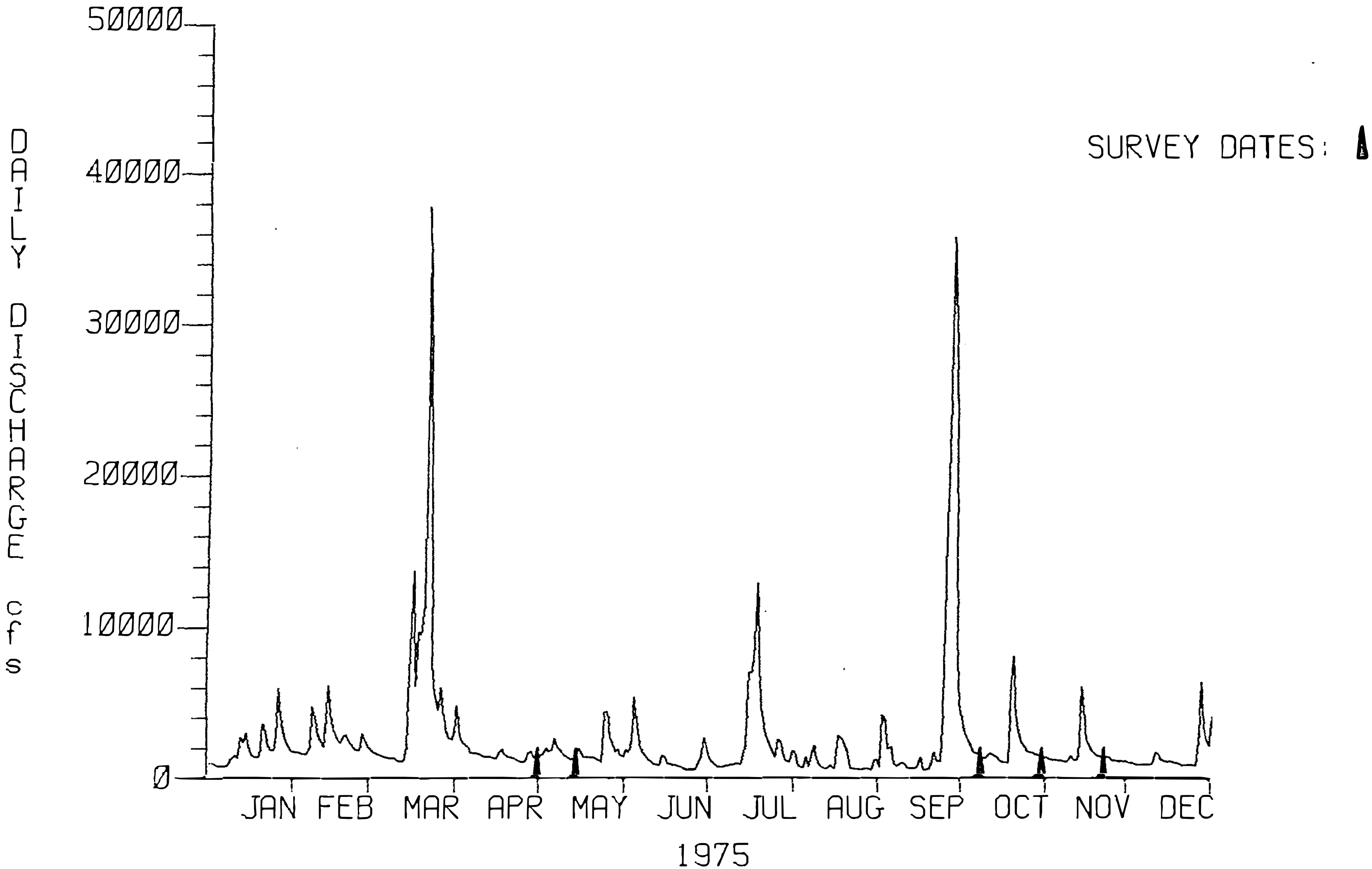


Figure 6f. Fresh Water Discharge and Slack Water Survey Dates, 1975

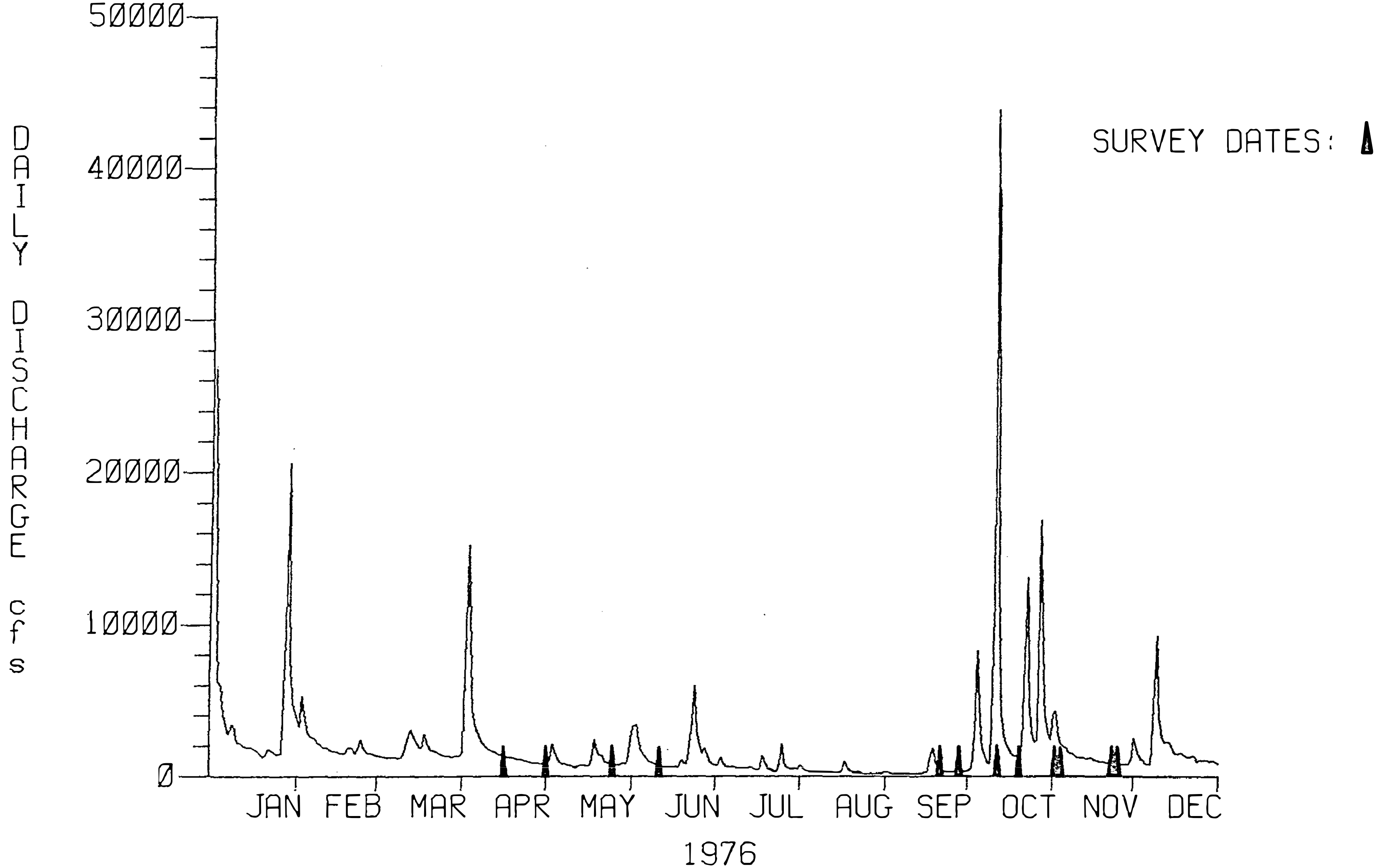


Figure 6g. Fresh Water Discharge and Slack Water Survey Dates, 1976

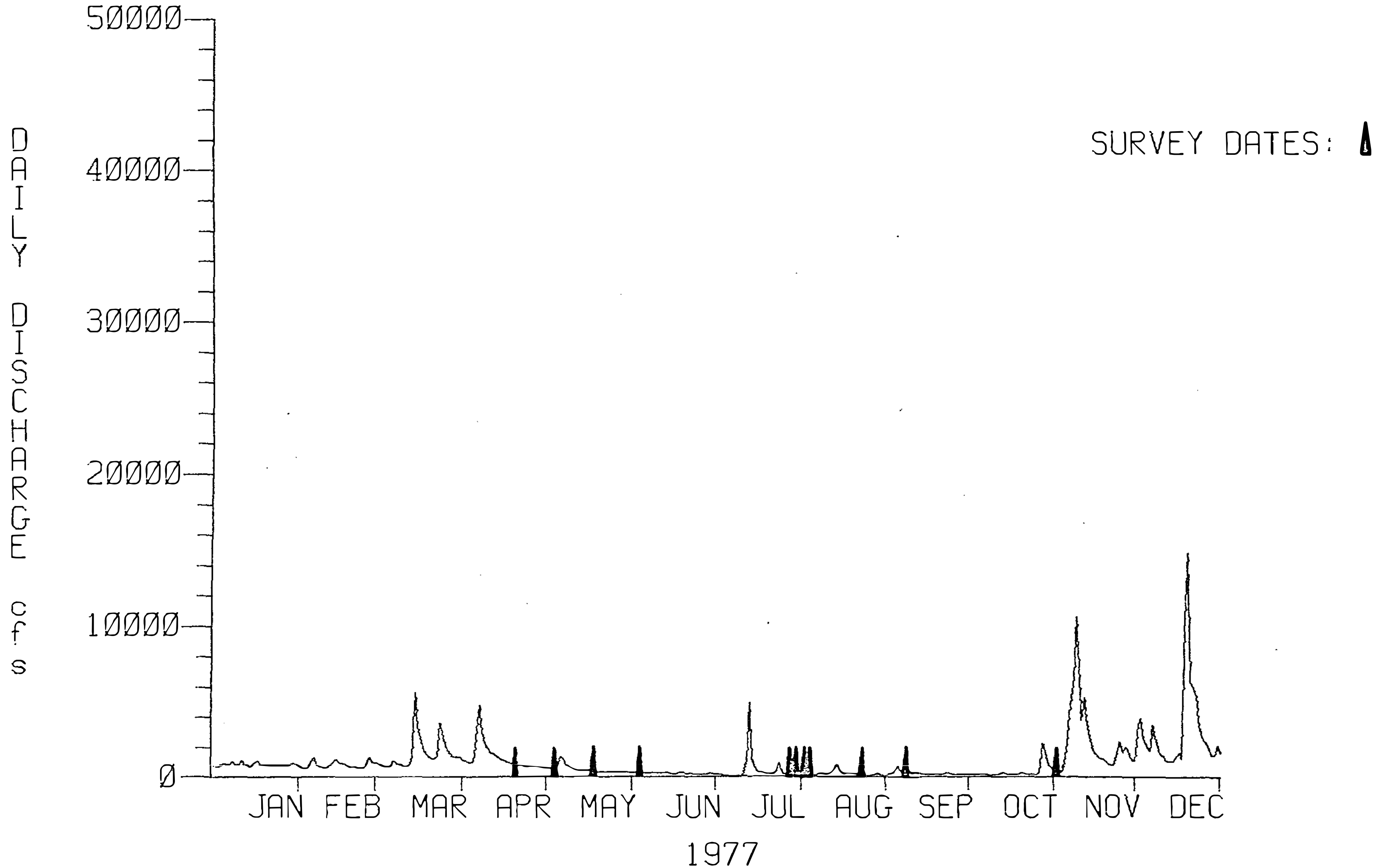


Figure 6h. Fresh Water Discharge and Slack Water Survey Dates, 1977

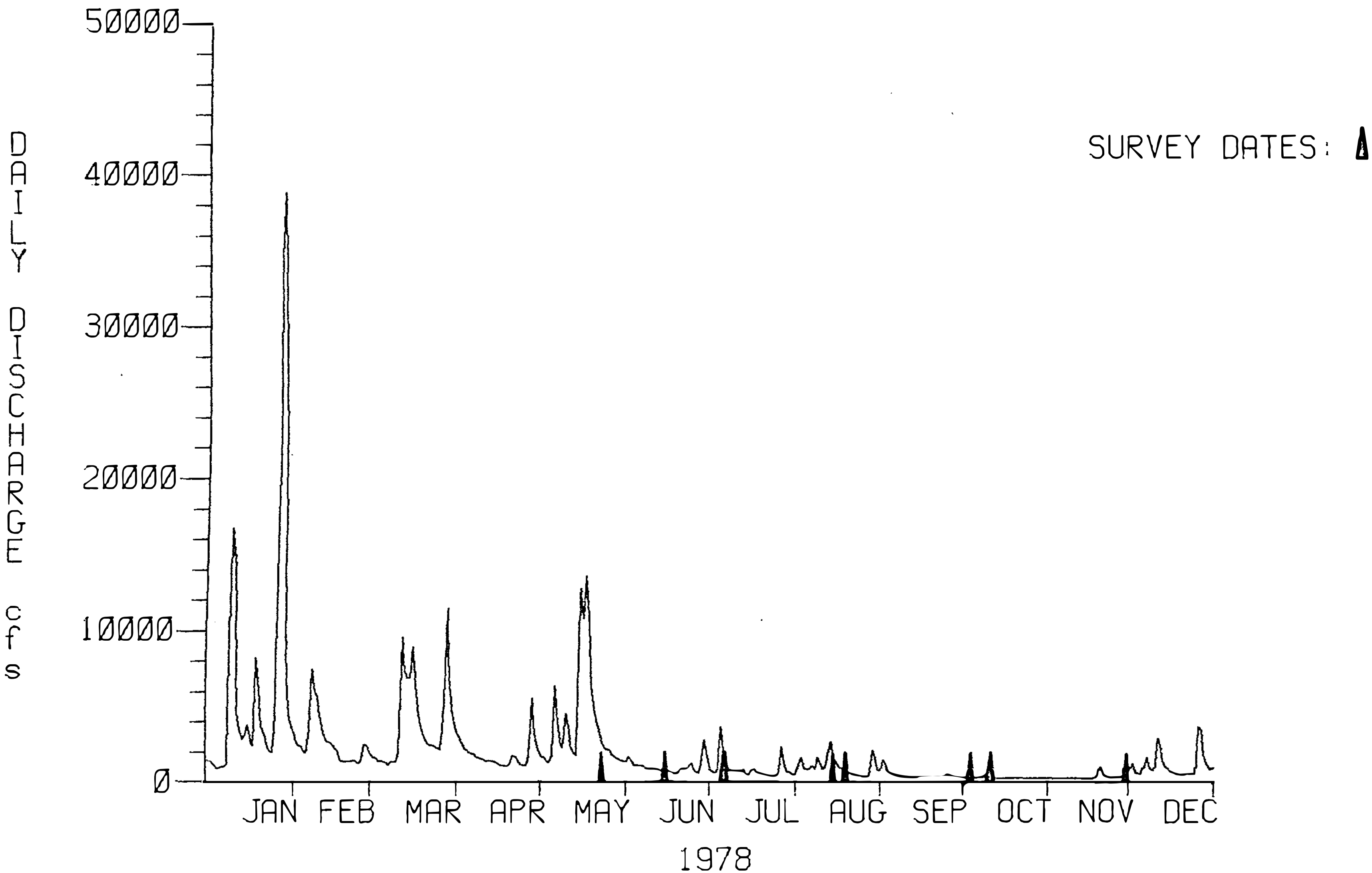


Figure 6i. Fresh Water Discharge and Slack Water Survey Dates, 1978

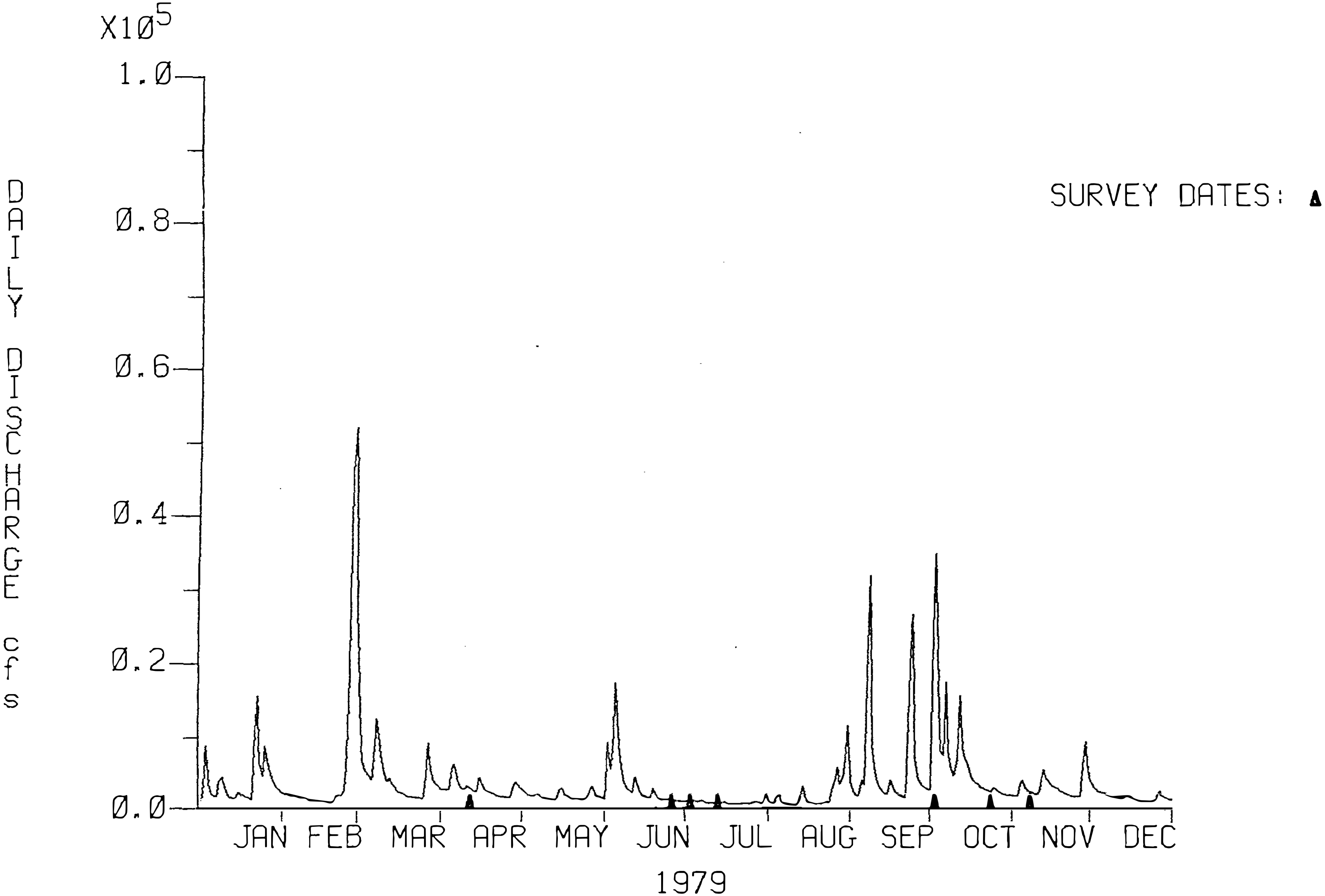


Figure 6j. Fresh Water Discharge and Slack Water Survey Dates, 1979

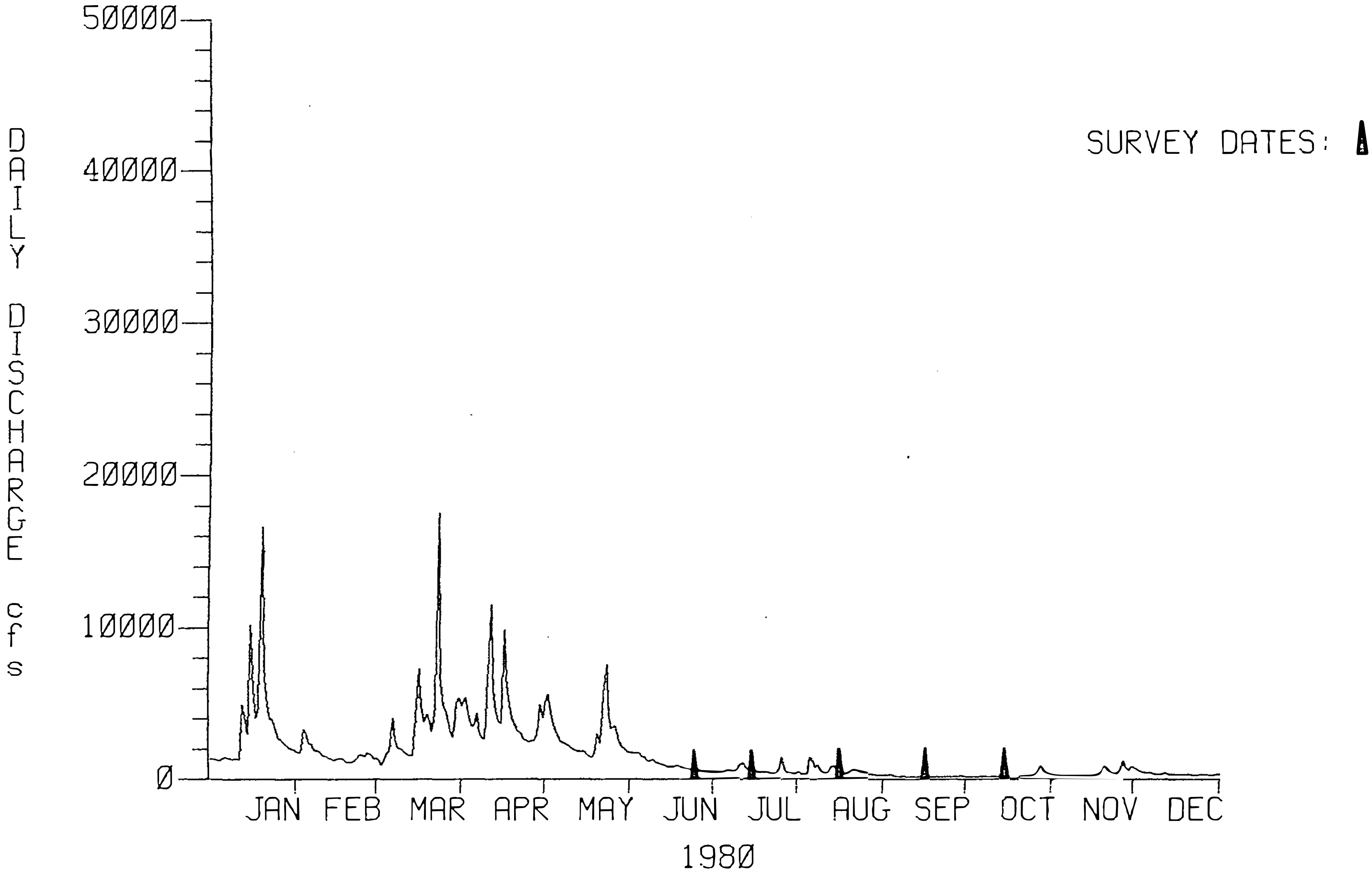


Figure 6k. Fresh Water Discharge and Slack Water Survey Dates, 1980

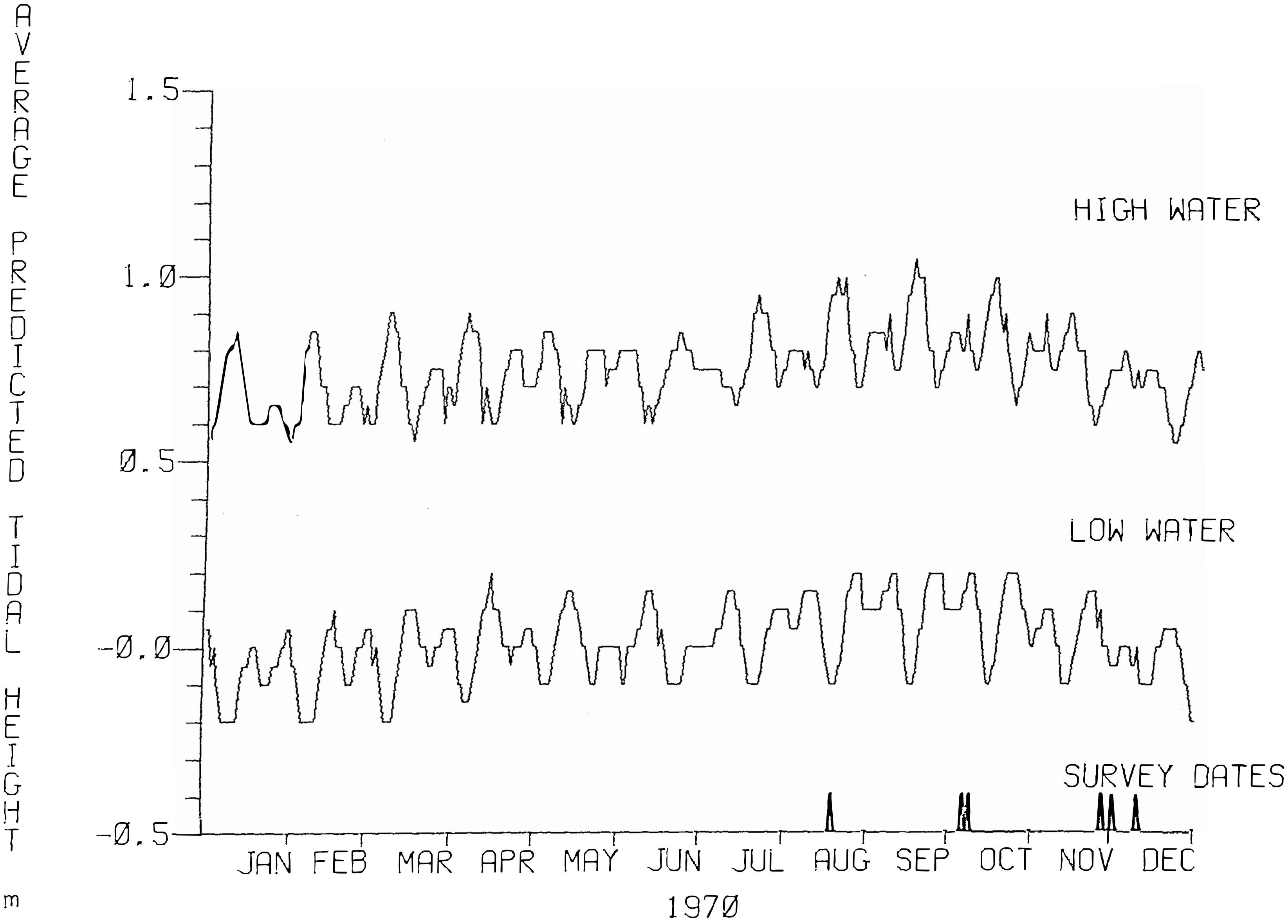


Figure 7a. Average Predicted Tide and Slack Water Survey Dates, 1970

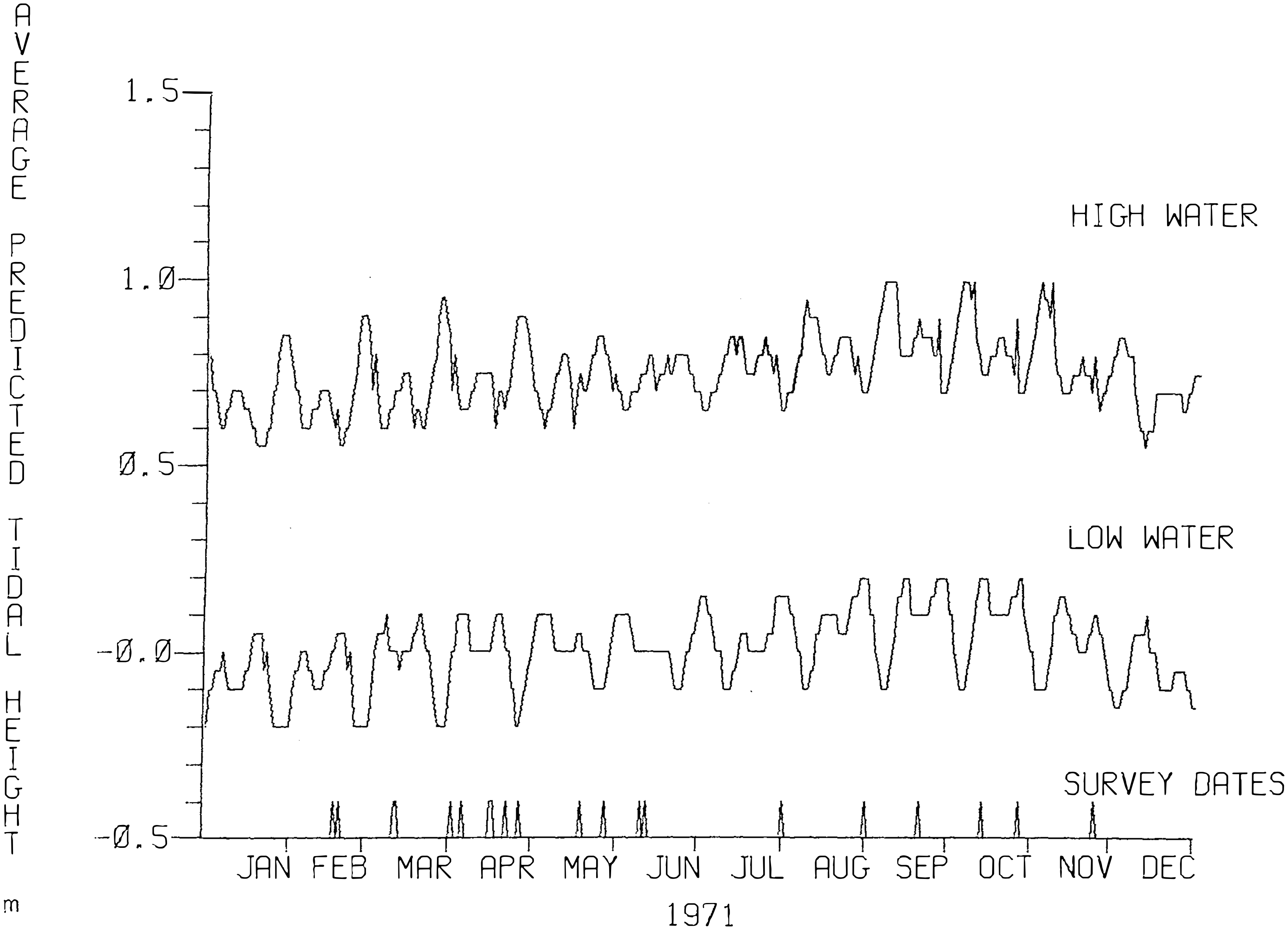


Figure 7b. Average Predicted Tide and Slack Water Survey Dates, 1971

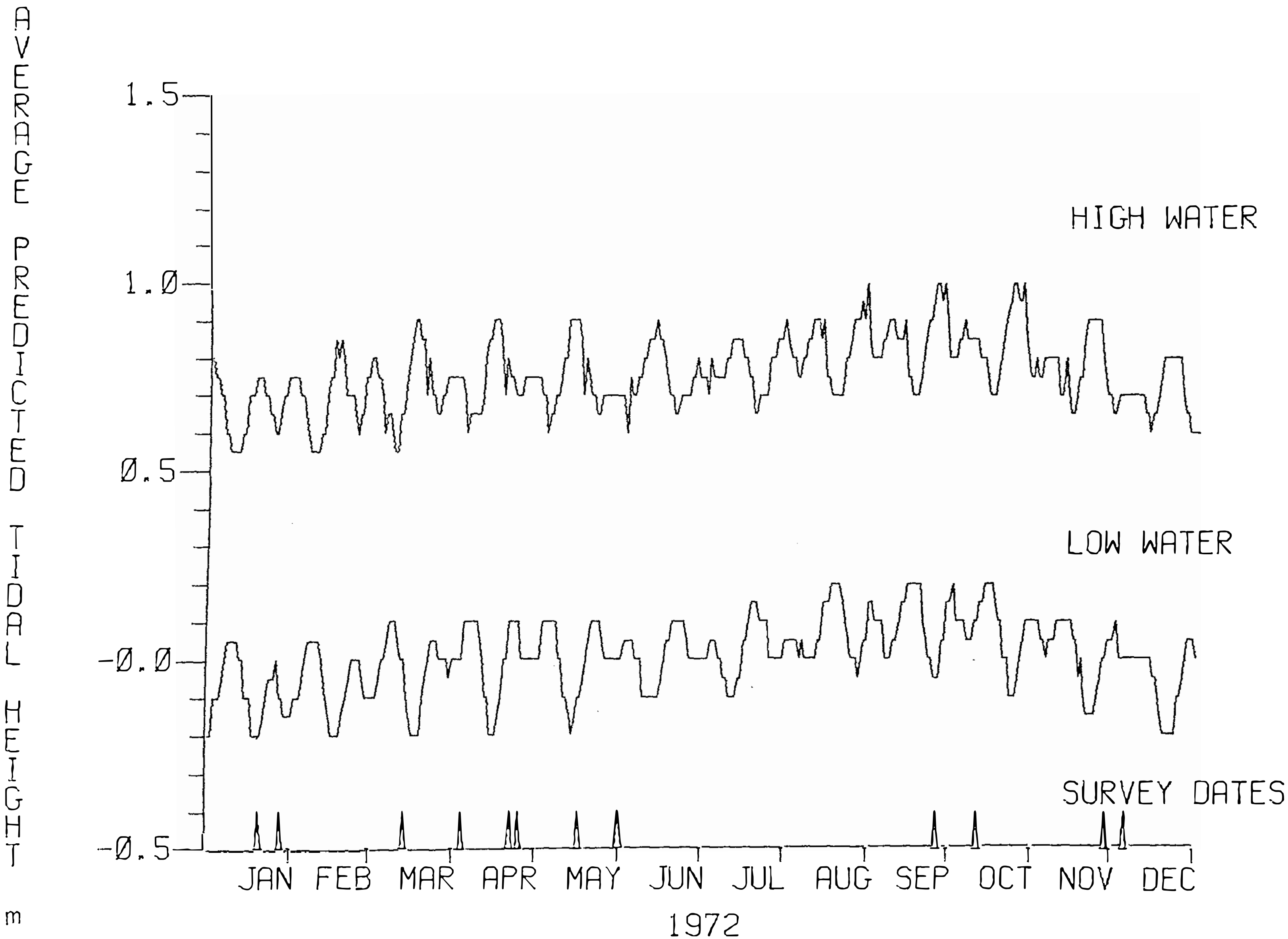


Figure 7c. Average Predicted Tide and Slack Water Survey Dates, 1972

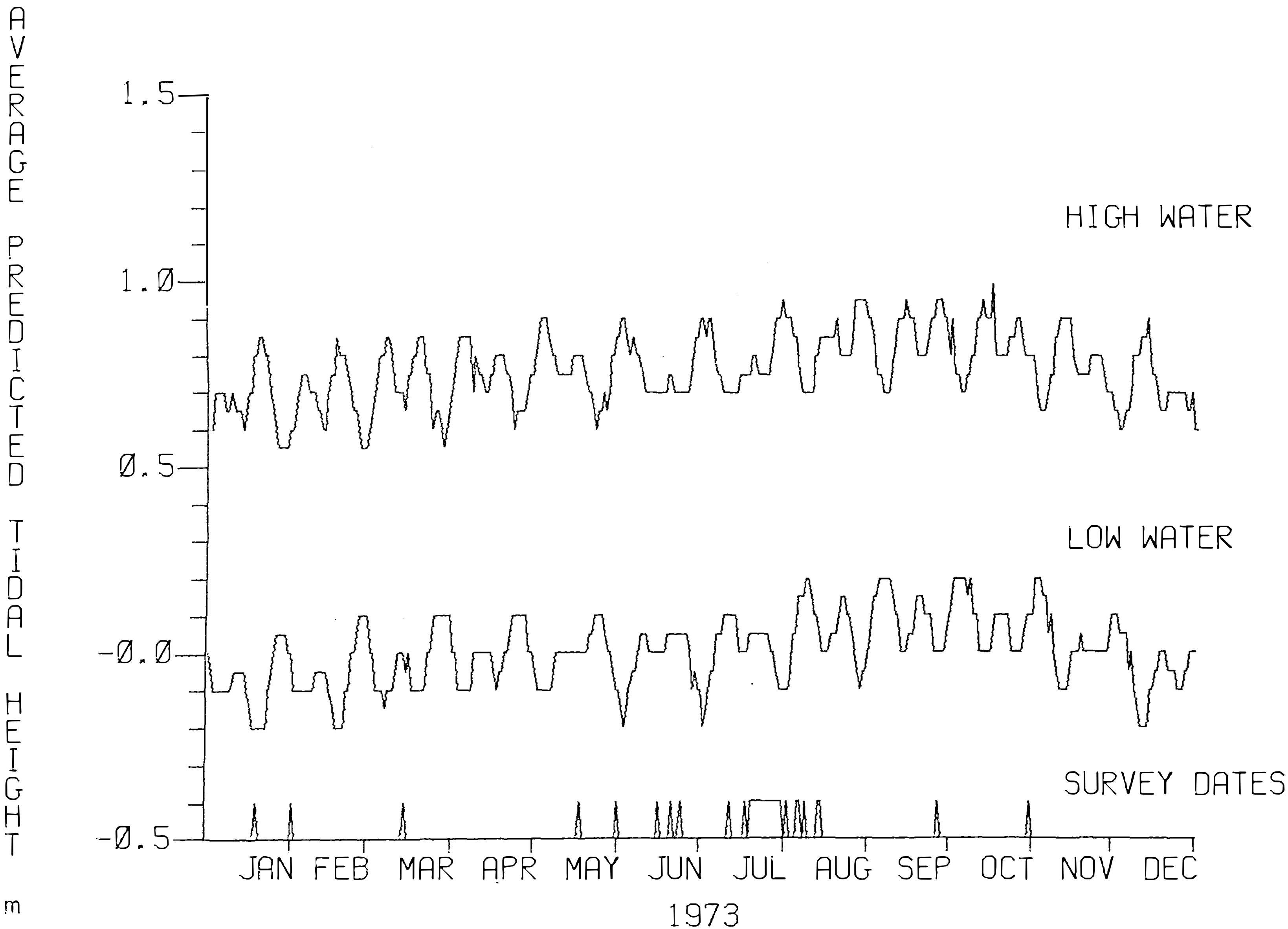


Figure 7d. Average Predicted Tide and Slack Water Survey Dates, 1973

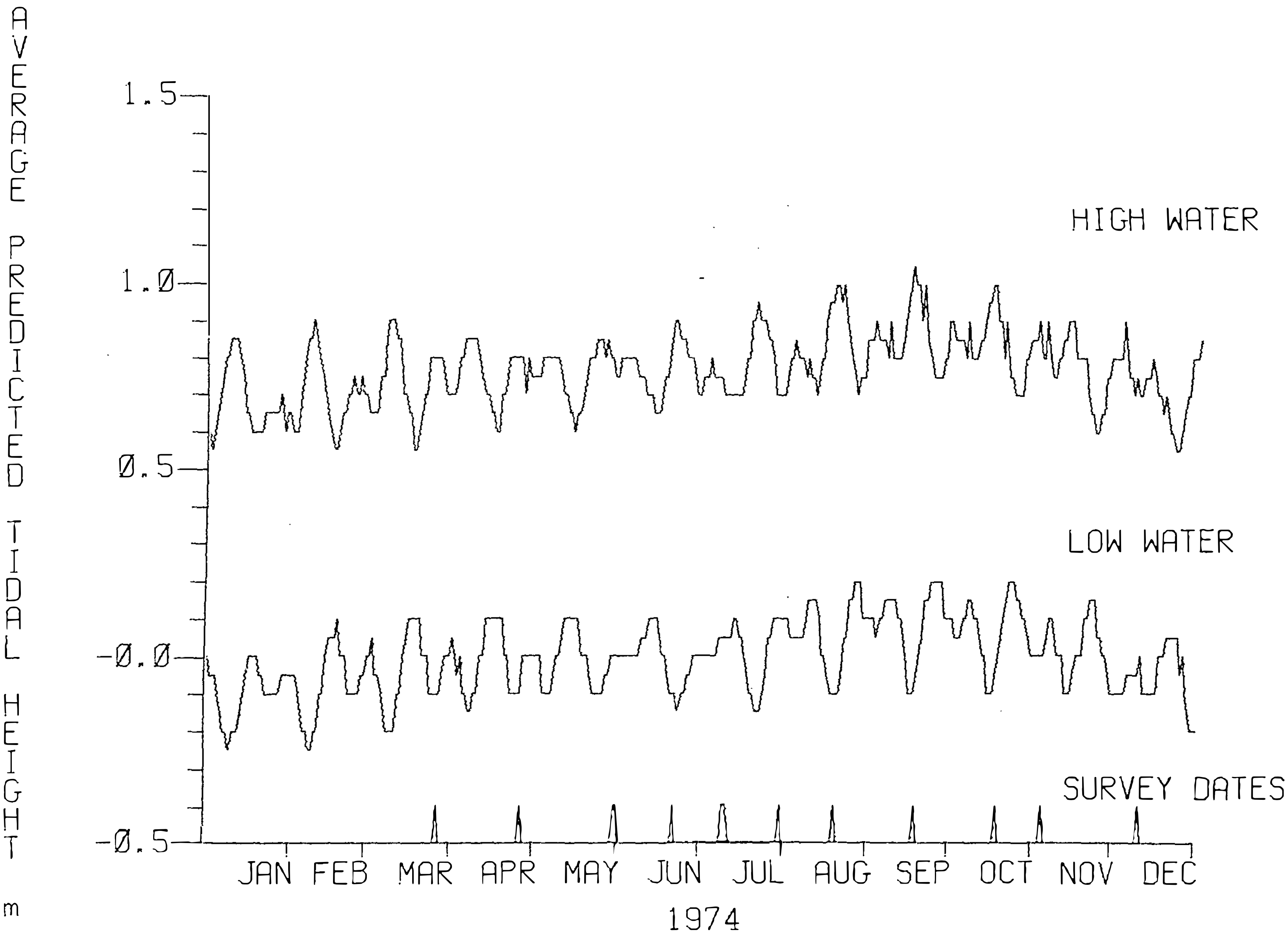


Figure 7e. Average Predicted Tide and Slack Water Survey Dates, 1974

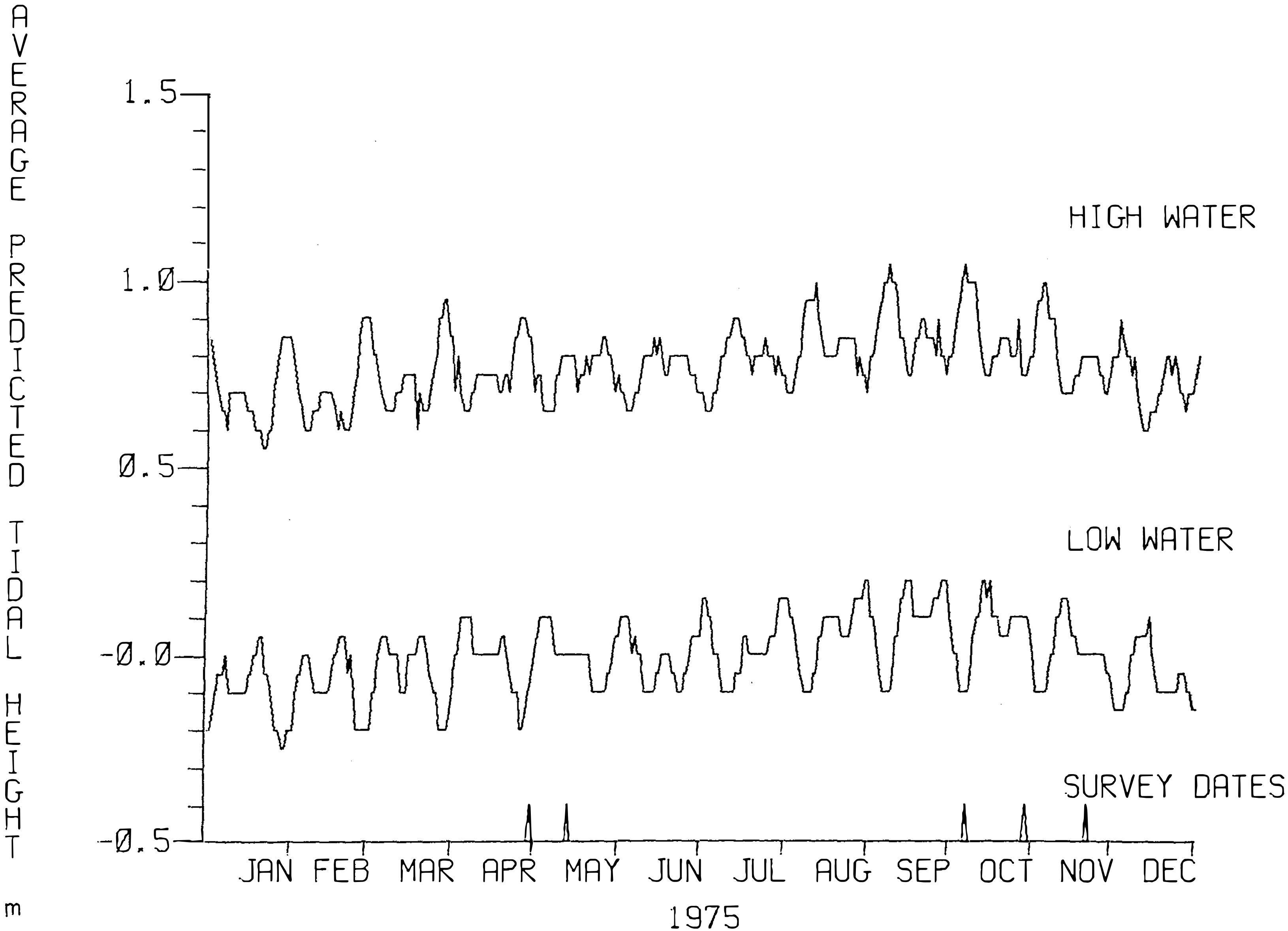


Figure 7f. Average Predicted Tide and Slack Water Survey Dates, 1975

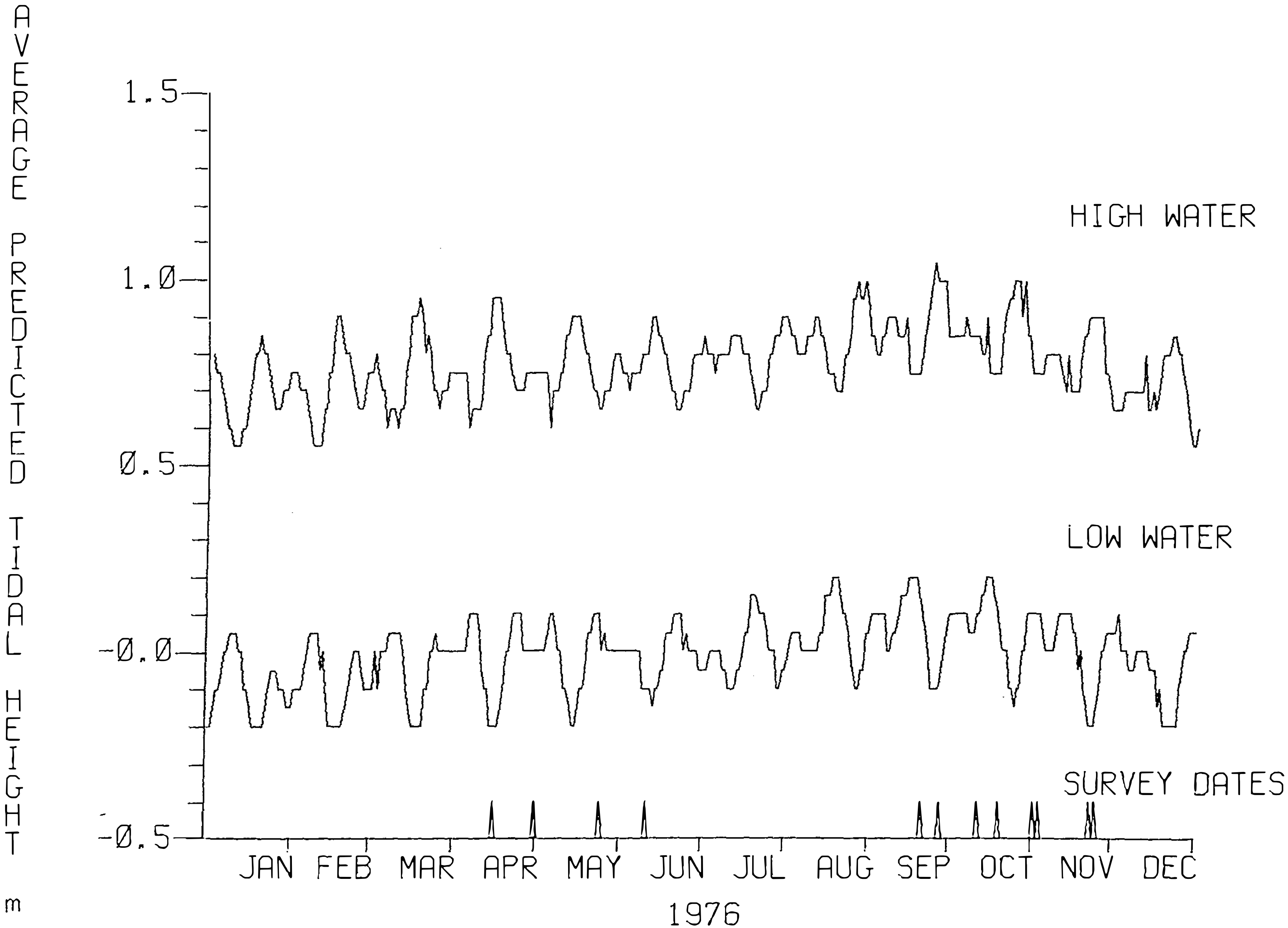


Figure 7g. Average Predicted Tide and Slack Water Survey Dates, 1976

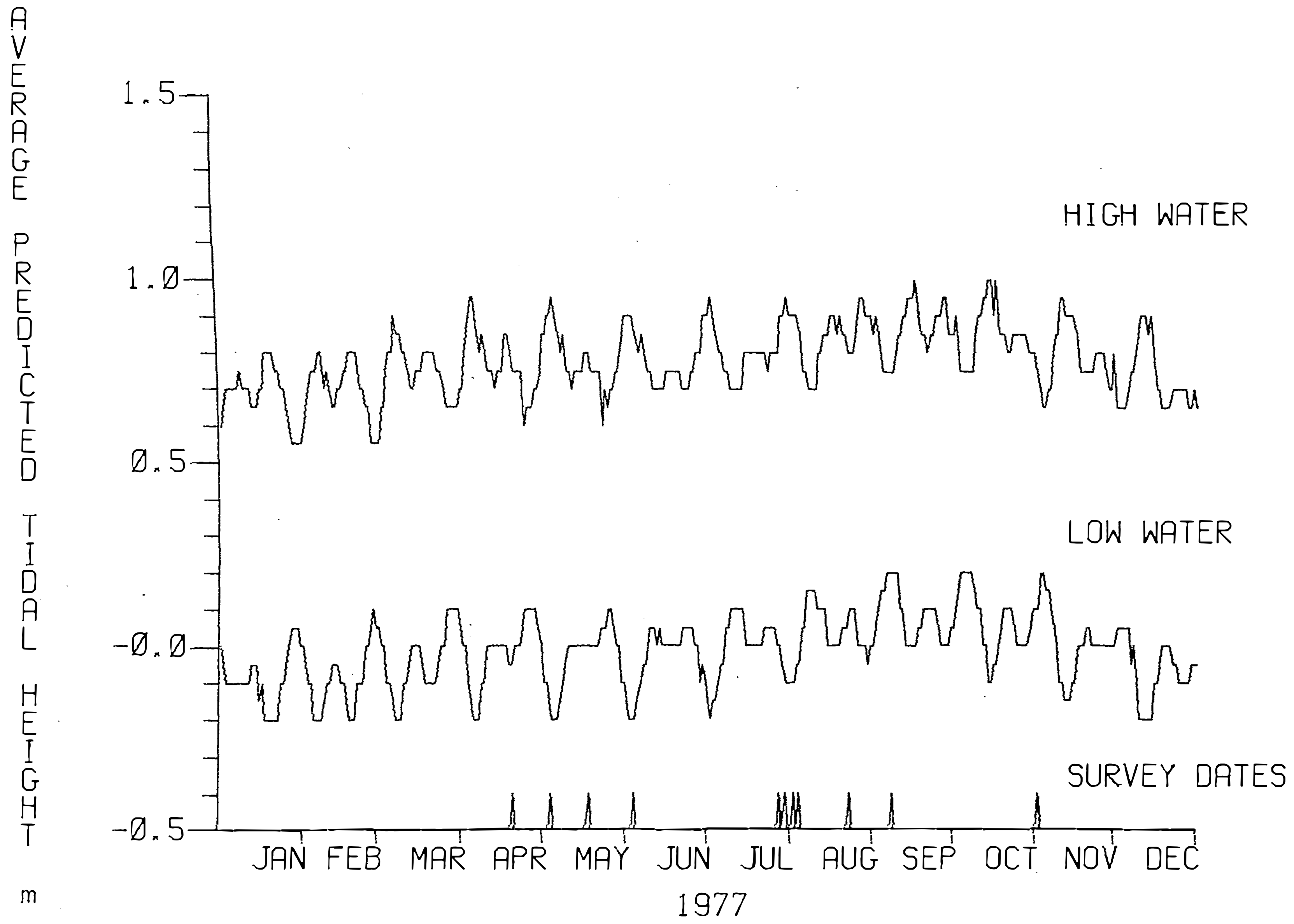


Figure 7h. Average Predicted Tide and Slack Water Survey Dates, 1977

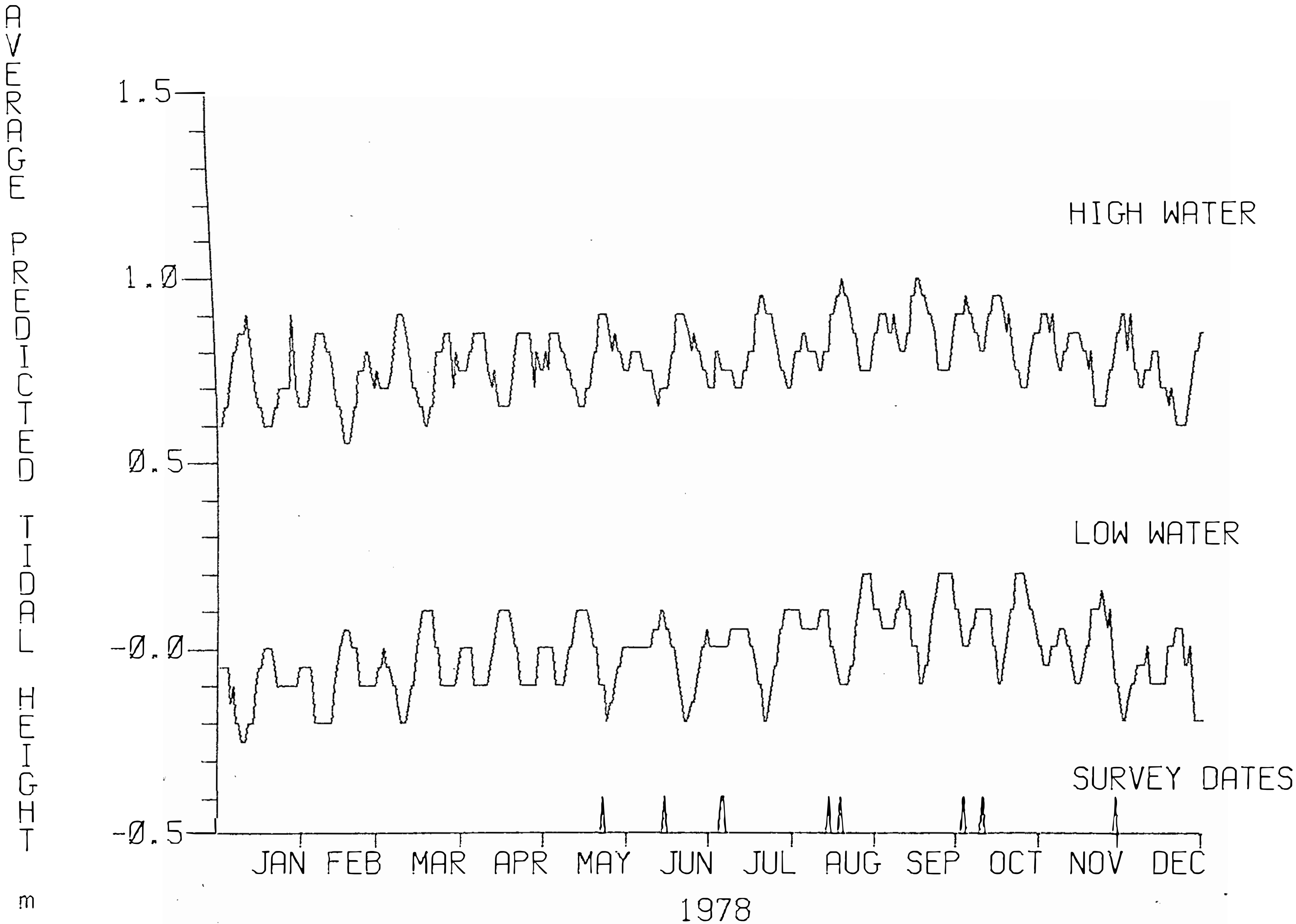


Figure 7i. Average Predicted Tide and Slack Water Survey Dates, 1978

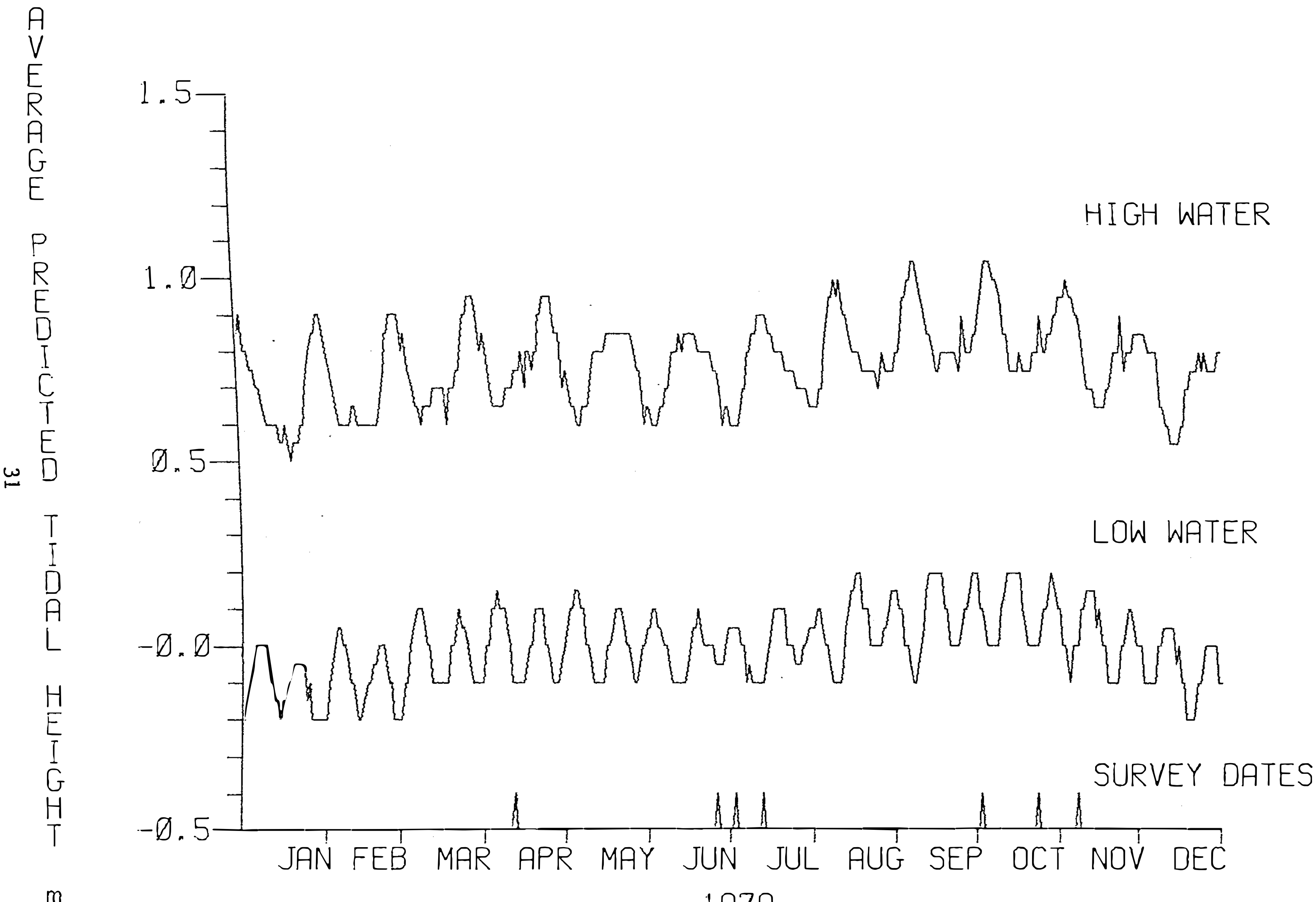


Figure 7j. Average Predicted Tide and Slack Water Survey Dates, 1979

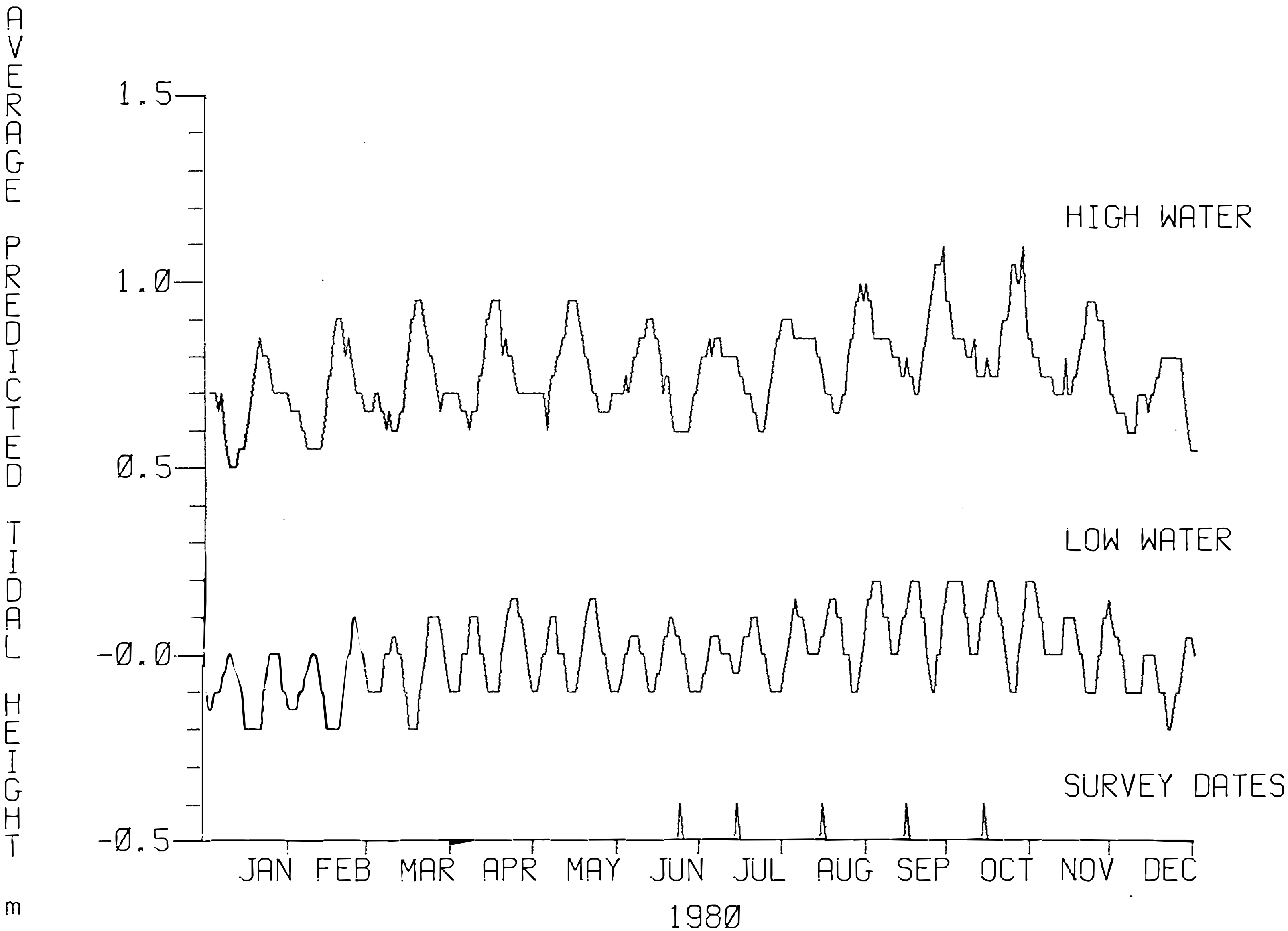


Figure 7k. Average Predicted Tide and Slack Water Survey Dates, 1980

Sampling depths vary with the parameter being considered. Temperature, conductivity, and salinity are sampled every two meters between the surface and the bottom. Dissolved oxygen samples are collected at the surface, mid-depth, and bottom. Biochemical oxygen demand, nutrients, and chlorophyll 'a' samples are collected at the surface and bottom.

Temperature measurements are made with either an Interocean Model 513 CTD instrument or a Hydrolab Model ARA ET-100 thermistor. Conductivity measurements are made with a modified Interocean Model 513 CTD instrument. Water samples for the other analyses are collected by pumping water with a modified bilge pump from the desired sampling depth or with a weighted 5-liter PVC Frautschy bottle attached to a metered line. The bottle is lowered by the hand line to the desired sampling depth, then closed by a messenger and pulled to the surface. At the surface, the water is placed in appropriate containers for various laboratory analyses. While in the field, the instrument readings and sample bottle numbers are recorded on an Oceanography Form 1 as illustrated in Figure 8.

D. Sample Handling Procedures

Samples for salinity are placed in 125-ml sample-rinsed glass bottles. When brought back to the laboratory the samples are run on an Industrial Instrument Laboratory Salinometer Model RS7A. Salinity is sometimes calculated

OCEANOGRAPHY FORM 1 (REVISED 1977)

CRUISE	STATION	DATE: DAY		MO.		YR.		STATION TIME E.S.T.			LAT. N.: DEG.		MIN.		1/10	LONG. W.: DEG.		MIN.		1/10	CRUISE DESIGNATION					CARD CODE						
RAPPAHANNOCK	57.79	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
OBSERVERS: CLARK	TIME: 1040	1	2	0	7	7	9	0	9	6	3	7	5	2	5	7	6	4	6	4	0	5	R	0	4	0	0	9	7	5	0	5

RIVER CODE		STATION LOCATION					VESS. CODE		DEPTH TO BOTTOM				TIDE	DISK VIS.		WIND DIR.		WIND SPD.		AIR TEMP in DEGREES				FREE FORM FIELD (56–80)
32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56–80
R	A	R	5	7	.	8	T	H	0	0	0	6	L	0	4									

DEPTH	SAMPLE TIME	CODE	FINAL	CODE	FINAL	CODE	FINAL	CODE	FINAL	CODE	FINAL	CODE	FINAL	CODE	FINAL
1.0		GJ	27.00	8J	9.10			6A	7.5						
3.0		GJ	26.60	8J	9.20			6A	4.8						
5.0		GJ	25.40	8J	9.50			6A	6.7						
			Corrected Temperatures		Corrected Conductivity				Dissolved Oxygen						

DEPTH	TEMP.	CONDUCTIVITY	SALINITY	D.O.	B.O.D.	NUTRIENTS	CHLOROPHYLL	COLIFORM	-------	INST. CODE
1	27.0	9.1		K020						CSTD
3	26.6	9.2		K019						ARA
5	25.4	9.5		K018						---
7	Field Data									PG__OF__

Figure 8. Sample Oceanography Form 1

from temperature and conductivity readings taken from the Interocean Model 513 CTD instrument.

Samples for dissolved oxygen analysis are placed in 125-ml sample-rinsed glass bottles. Reagents are added immediately in preparation for the azide modification of the Winkler procedure to be conducted later in the laboratory.

Biochemical oxygen demand (BOD) samples are collected in standard 300 ml glass stoppered BOD bottles. Nutrient samples are collected in 1 liter plastic "cubitainers". Chlorophyll samples are collected in opaque plastic containers. All three types of samples are placed on ice immediately after collection and until they can be processed in the laboratory. Nutrient and chlorophyll samples are filtered within 24 hours of collection. The details of the laboratory procedures and analytical methods can be found in other VIMS reports such as "Water Quality in the York River" (Sturm and Neilson, 1977).

E. Data Reduction and Storage

Central to the reduction of data collected by the Department of Physical Oceanography and Hydraulics is the Oceanography Form 1. The Form 1 serves the dual purpose of providing a sheet for field and laboratory use as well as a form from which oceanographic data may be entered to the computer-based storage system via either punched cards or magnetic tape.

The data are available on request. Printouts of work done by the Department of Physical Oceanography and Environmental Engineering are kept in the department library and in the VIMS library.

II. DISCUSSION

A. River Discharge

Rappahannock River discharge, measured near Fredericksburg, during the 1970-1980 study period covered a wide range of values. The maximum daily average discharge of 8.42×10^4 cfs (2526 cms) occurred on 22 June 1972 due to the heavy rains of Tropical Storm Agnes. Minimum daily average discharge was 84 cfs (2.52 cms) and occurred on 7 July 1977. Mean daily freshwater flow near Fredericksburg, during the study period, averaged 2091 cfs (62.73 cms). The greatest total discharge for a given year during the 11 year study was 1.28×10^6 cubic feet (3.84×10^4 cubic meters) in 1979. The year with the least total discharge was 1977 with 3.62×10^5 cubic feet (1.086×10^4 cubic meters).

B. Temperature

Water temperatures in the Rappahannock River showed a seasonal pattern following the air temperature pattern through the year. Minimum temperatures around 3^oC were observed in February. The water temperatures increased through the spring reaching maximum temperatures around 28^oC in August. Water temperatures declined in September and continued to decrease through the fall.

C. Salinity

Salinity in the Rappahannock River decreased from the mouth to the head of the estuary. The salt content of the water tended to increase with depth.

Salt regularly intruded from the Cheseapeake Bay to the region around kilometer 90. Disregarding a few instances of localized upstream phenomena, the 1970-1980 slack water data set showed a maximum intrusion of the 1 ppt isohaline as far upstream as kilometer 109. The minimum intrusion of the 1 ppt isohaline was around kilometer 49. This report does not include data from the study of Tropical Storm Agnes. That study reported a minimum intrusion distance of 46 kilometers (Andersen, Davis, Lynch, Schubel (ed.), 1973). In addition to longitudinal movements of the salinity intrusion, salinity has also undergone variable degrees of vertical stratification.

D. Dissolved Oxygen

The dissolved oxygen concentration in an estuary is dependent on several physical and biological factors. The solubility of oxygen is influenced by temperature and salinity. Turbulence affects atmospheric reaeration rates. Metabolism and the decomposition of organic material exert demands on the available oxygen.

The dissolved oxygen values in the Rappahannock River showed a seasonal pattern. The highest values, around 10 mg/l, were reported in the winter during the time of low temperatures and reduced oxygen demand. The level of dissolved oxygen decreased through the spring reaching minimum values around 6.5 mg/l in the summer during the season of low fresh water discharge and increased temperatures and salinities.

The State Water Control Board has set the water quality standards for acceptable levels of dissolved oxygen (State Water Control Board, 1980). The minimum allowable oxygen concentration for estuarine waters is 4.0 mg/l. The daily average concentrations should exceed 5.0 mg/l. Although the dissolved oxygen values in the Rappahannock River were generally above these levels, values less than 4.0 mg/l have occurred between May and October. The minimum value recorded was 0.0 mg/l which occurred at kilometer 28 on 31 July 1971.

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APPENDICES

A. Longitudinal Contours

B. Temperature (^{o}C)

C. Salinity (ppt)

D. Dissolved Oxygen (mg/l)

A. LONGITUDINAL CONTOURS

Longitudinal contours of temperature, salinity and dissolved oxygen have been generated for each of the slack water surveys. A listing of these surveys is contained in Table 3. The bottom profile is based on the water depth at mean low water as taken from National Ocean Survey charts at the most frequently sampled slack water stations.

Temperature, salinity, and dissolved oxygen values are recorded at each depth sampled. When the sampling is taken at an angle to the vertical because of bottom currents or sampling is slightly off-station, the sampled bottom depth can be deeper than the bottom profile. In this case, the sampling depths for the entire cast at that station are scaled so the bottom depths correspond to each other. When the bottom depth sampled is shallower than the bottom of the profile, the sample depths are used as recorded.

SURFACE II is a computer software system developed by the Kansas Geological Survey for computer contouring and graphics display. The user is able to specify plotting options by selecting appropriate operation commands. The isotherms, isohalines, and lines of constant dissolved oxygen in this report have been drawn using a SURFACE II plotting package and Tectronix plotter. When a parameter has been measured by more than one method the most complete data set is used.

Table 3. Dates of Slack Water Surveys and Contours Generated
Rappahannock River

DATE D/M/Y	CRUISE	SLACK	TEMPERATURE	SALINITY	DISSOLVED OXYGEN
180870	OSR01	H	T	S	D
061070	OSR02	L	T	S	D
081070	OSR03	H	T	S	N
271170	OSR04	L	T	N	D
011270	OSR05	L	T	S	N
101270	OSR06	H	T	S	N
170271	OSR01	L	T	S	N
190271	OSR02	H	T	S	N
110371	OSR03	H	T	S	N
120371	OSR04	L	T	S	N
010471	OSR05	L	T	S	N
050471	OSR06	H	T	S	D
150471	OSR07	L	T	S	D
160471	OSR08	H	T	N	D
210471	OSR09	H	T	S	D
260471	OSR10	L	T	N	D
180571	OSR11	H	T	S	D
270571	OSR12	L	T	S	D
090671	OSR13	L	T	N	D
110671	OSR14	L	T	S	D
310771	OSR15	H	T	S	D
310871	OSR16	H	T	S	D
200971	OSR17	L	T	S	D
131071	OSR18	L	N	S	D
271071	OSR19	L	T	S	D
241171	OSR20	H	T	N	N
200172	OSR01	L	T	S	D
280172	OSR02	L	T	S	D
130372	OSR03	L	T	S	D
030472	OSR04	L	T	S	D
210472	OSR05	H	T	S	D
240472	OSR06	H	T	S	D
160572	OSR07	L	T	N	N
310572	OSR08	H	T	N	D
260972	OSR09	L	T	S	D
111072	OSR10	L	T	S	D
281172	OSR11	L	T	S	D
051272	OSR12	H	T	S	N

H: HIGH WATER SLACK, SLACK BEFORE EBB
T: TEMPERATURE GENERATED
S: SALINITY GENERATED
L: LOW WATER SLACK, SLACK BEFORE FLOOD
D: DISSOLVED OXYGEN GENERATED
N: NO CONTOUR GENERATED (NO DATA AVAILABLE OR NOT ENOUGH TO CONTOUR)

Table 3. (Cont'd)

DATE D/M/Y	CRUISE	SLACK	TEMPERATURE	SALINITY	DISSOLVED OXYGEN
190173	OSR01	H	T	S	N
010273	OSR02	H	T	S	N
140373	OSR03	H	T	S	N
170573	OSR29	L	N	N	N
310573	OSR04	H	T	S	D
310573	OSR30	L	N	N	N
150673	OSR31	L	N	N	N
200673	OSR32	L	N	N	N
230673	OSR33	L	N	N	N
110773	OSR05	H	T	S	D
170773	OSR34	L	N	N	N
190773	OSR06	H	N	N	N
190773	OSR07	L	N	N	N
190773	OSR08	H	N	N	N
200773	OSR09	H	N	N	N
200773	OSR10	L	N	N	N
210773	OSR11	L	N	N	N
220773	OSR12	H	N	N	N
230773	OSR13	H	N	N	N
240773	OSR14	H	N	N	N
240773	OSR15	L	N	N	N
250773	OSR16	H	N	N	N
260773	OSR17	H	N	N	N
270773	OSR18	H	N	N	N
280773	OSR19	H	N	N	N
290773	OSR20	H	N	N	N
300773	OSR35	L	N	N	N
300773	OSR21	H	N	N	N
010873	OSR22	L	N	N	N
010873	OSR36	L	N	N	N
050873	OSR37	L	N	N	N
060873	OSR23	L	N	N	N
080873	OSR24	H	T	S	D
130873	OSR25	L	T	S	D
140873	OSR26	H	T	S	D
260973	OSR27	L	T	S	D
301073	OSR28	L	T	S	D

H: HIGH WATER SLACK, SLACK BEFORE EBB

T: TEMPERATURE GENERATED

S: SALINITY GENERATED

L: LOW WATER SLACK, SLACK BEFORE FLOOD

D: DISSOLVED OXYGEN GENERATED

N: NO CONTOUR GENERATED (NO DATA AVAILABLE OR NOT ENOUGH TO CONTOUR)

Table 3. (Cont'd)

DATE D/M/Y	CRUISE	SLACK	TEMPERATURE	SALINITY	DISSOLVED OXYGEN
190173	OSR01	H	T	S	N
010273	OSR02	H	T	S	N
140373	OSR03	H	T	S	N
170573	OSR29	L	N	N	N
310573	OSR04	H	T	S	D
310573	OSR30	L	N	N	N
150673	OSR31	L	N	N	N
200673	OSR32	L	N	N	N
230673	OSR33	L	N	N	N
110773	OSR05	H	T	S	D
170773	OSR34	L	N	N	N
190773	OSR06	H	N	N	N
190773	OSR07	L	N	N	N
190773	OSR08	H	N	N	N
200773	OSR09	H	N	N	N
200773	OSR10	L	N	N	N
210773	OSR11	L	N	N	N
220773	OSR12	H	N	N	N
230773	OSR13	H	N	N	N
240773	OSR14	H	N	N	N
240773	OSR15	L	N	N	N
250773	OSR16	H	N	N	N
260773	OSR17	H	N	N	N
270773	OSR18	H	N	N	N
280773	OSR19	H	N	N	N
290773	OSR20	H	N	N	N
300773	OSR35	L	N	N	N
300773	OSR21	H	N	N	N
010873	OSR22	L	N	N	N
010873	OSR36	L	N	N	N
050873	OSR37	L	N	N	N
060873	OSR23	L	N	N	N
080873	OSR24	H	T	S	D
130873	OSR25	L	T	S	D
140873	OSR26	H	T	S	D
260973	OSR27	L	T	S	D
301073	OSR28	L	T	S	D

H: HIGH WATER SLACK, SLACK BEFORE EBB
T: TEMPERATURE GENERATED
S: SALINITY GENERATED
L: LOW WATER SLACK, SLACK BEFORE FLOOD
D: DISSOLVED OXYGEN GENERATED
N: NO CONTOUR GENERATED (NO DATA AVAILABLE OR NOT ENOUGH TO CONTOUR)

Table 3. (Cont'd)

DATE D/M/Y/	CRUISE	SLACK	TEMPERATURE	SALINITY	DISSOLVED OXYGEN
260374	OSR01	L	T	S	D
260474	OSR02	H	T	S	D
300574	OSR03	H	T	S	D
310574	OSR04	H	T	S	D
210674	OSR05	L	T	S	D
090774	OSR06	L	T	S	D
100774	OSR07	L	T	S	D
300774	OSR08	H	T	S	D
190874	OSR09	L	T	S	D
180974	OSR10	L	T	S	D
181074	OSR11	L	T	S	D
041174	OSR12	L	T	S	D
101274	OSR13	H	T	S	N
290475	OSR01	L	T	S	D
130575	OSR02	L	T	S	D
071075	OSR03	L	T	S	D
291075	OSR04	H	T	S	D
211175	OSR05	L	T	S	N
150476	OSR01	L	T	S	D
300476	OSR02	L	T	S	D
240576	OSR03	H	T	S	D
100676	OSR04	H	T	S	D
200976	OSR05	H	T	S	D
270976	OSR06	L	T	S	D
111076	OSR07	L	T	S	D
191076	OSR08	H	T	S	D
011176	OSR09	H	T	S	D
031176	OSR10	H	T	N	D
221176	OSR11	L	T	S	D
241176	OSR12	L	T	S	D

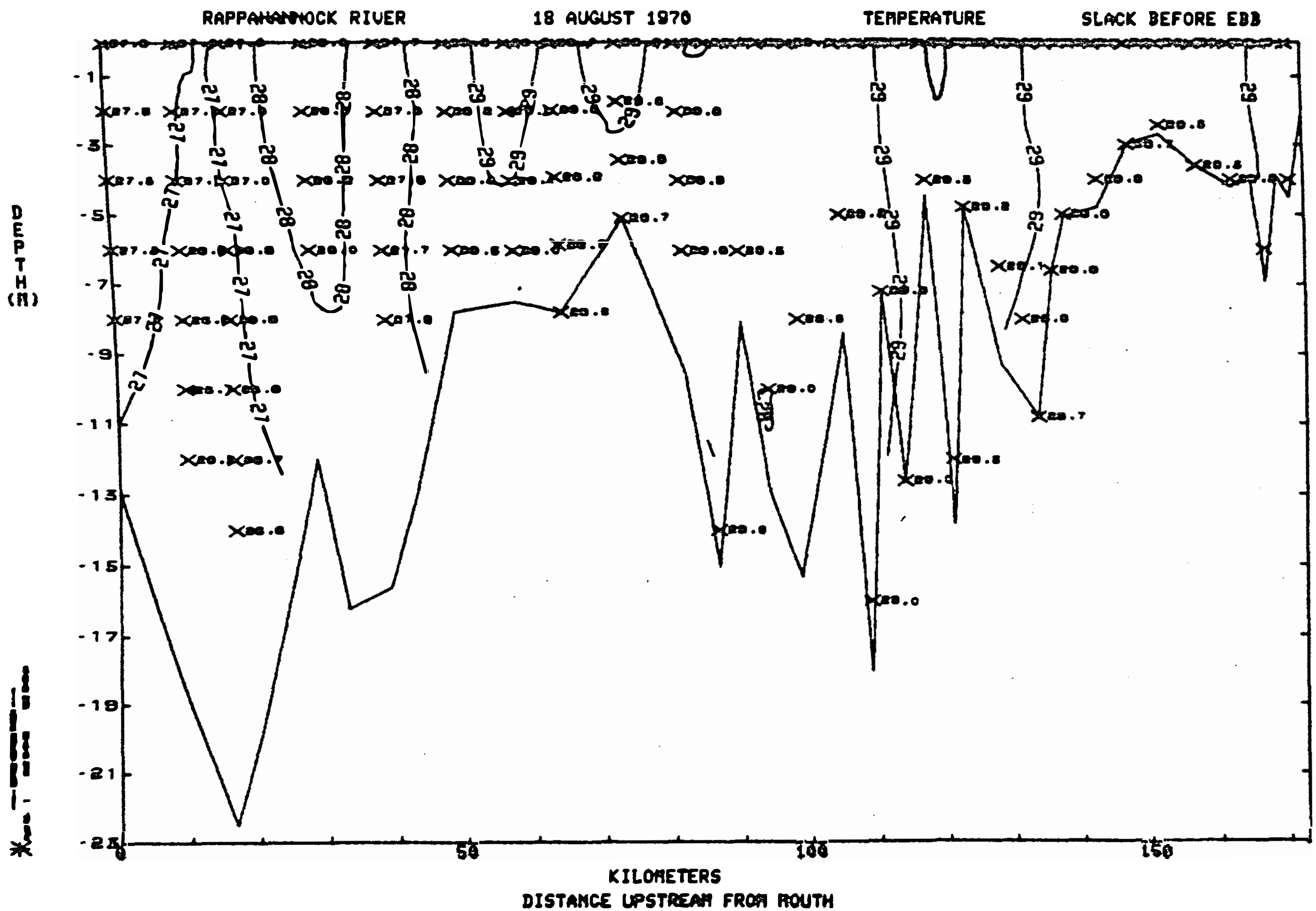
H: HIGH WATER SLACK, SLACK BEFORE EBB
T: TEMPERATURE GENERATED
S: SALINITY GENERATED
L: LOW WATER SLACK, SLACK BEFORE FLOOD
D: DISSOLVED OXYGEN GENERATED
N: NO CONTOUR GENERATED (NO DATA AVAILABLE OR NOT ENOUGH TO CONTOUR)

Table 3. (Cont'd)

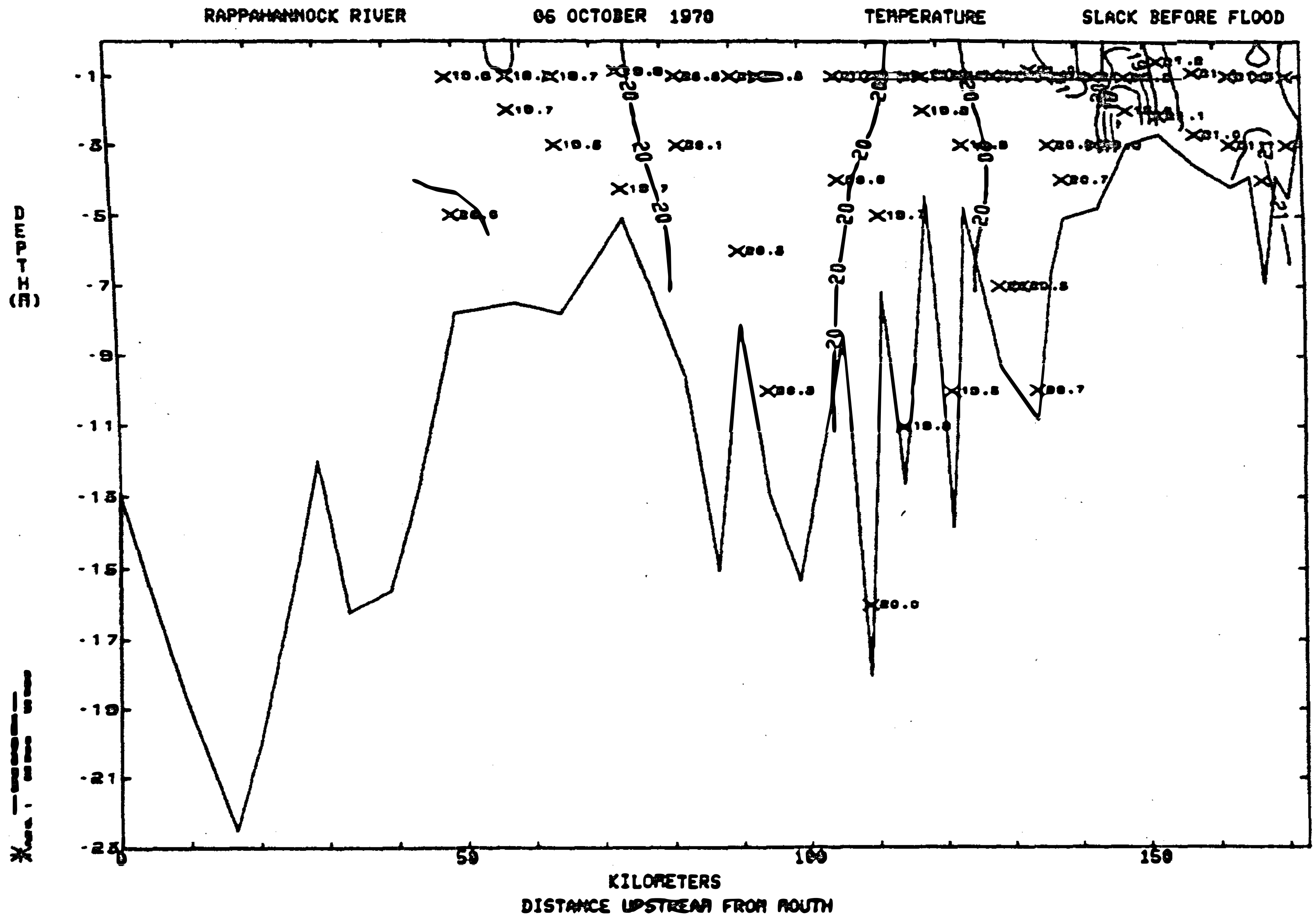
DATE M/D/Y	CRUISE	SLACK	TEMPERATURE	SALINITY	DISSOLVED OXYGEN
190477	OSR01	L	T	S	D
030577	OSR02	L	T	N	D
170577	OSR03	L	T	S	D
030677	OSR04	L	T	S	D
270777	OSR05	H	T	S	D
290777	OSR06	L	T	S	D
010877	OSR07	L	T	N	D
030877	OSR08	H	T	N	D
220877	OSR09	H	T	S	D
070977	OSR10	H	T	S	D
011177	OSR11	L	T	S	D
220578	OSR01	L	T	S	D
140678	OSR02	H	T	S	D
050778	OSR03	L	T	N	D
060778	OSR04	L	T	S	D
140878	OSR05	H	T	S	D
180878	OSR06	L	T	S	D
031078	OSR07	L	T	S	D
101078	OSR08	H	T	S	D
291178	OSR09	L	T	S	D
110479	OSR01	L	T	S	D
250679	OSR02	L	T	S	D
020779	OSR03	H	T	S	D
120779	OSR04	L	T	S	D
021079	OSR05	H	T	S	D
231079	OSR06	L	T	S	D
071179	OSR07	H	T	S	D
230680	OSR01	H	T	S	D
140780	OSR02	L	T	S	D
150880	OSR03	L	T	S	D
150980	OSR04	H	T	S	D
141080	OSR05	L	T	S	D

H: HIGH WATER SLACK, SLACK BEFORE EBB
T: TEMPERATURE GENERATED
S: SALINITY GENERATED
L: LOW WATER SLACK, SLACK BEFORE FLOOD
D: DISSOLVED OXYGEN GENERATED
N: NO CONTOUR GENERATED (NO DATA AVAILABLE OR NOT ENOUGH TO CONTOUR)

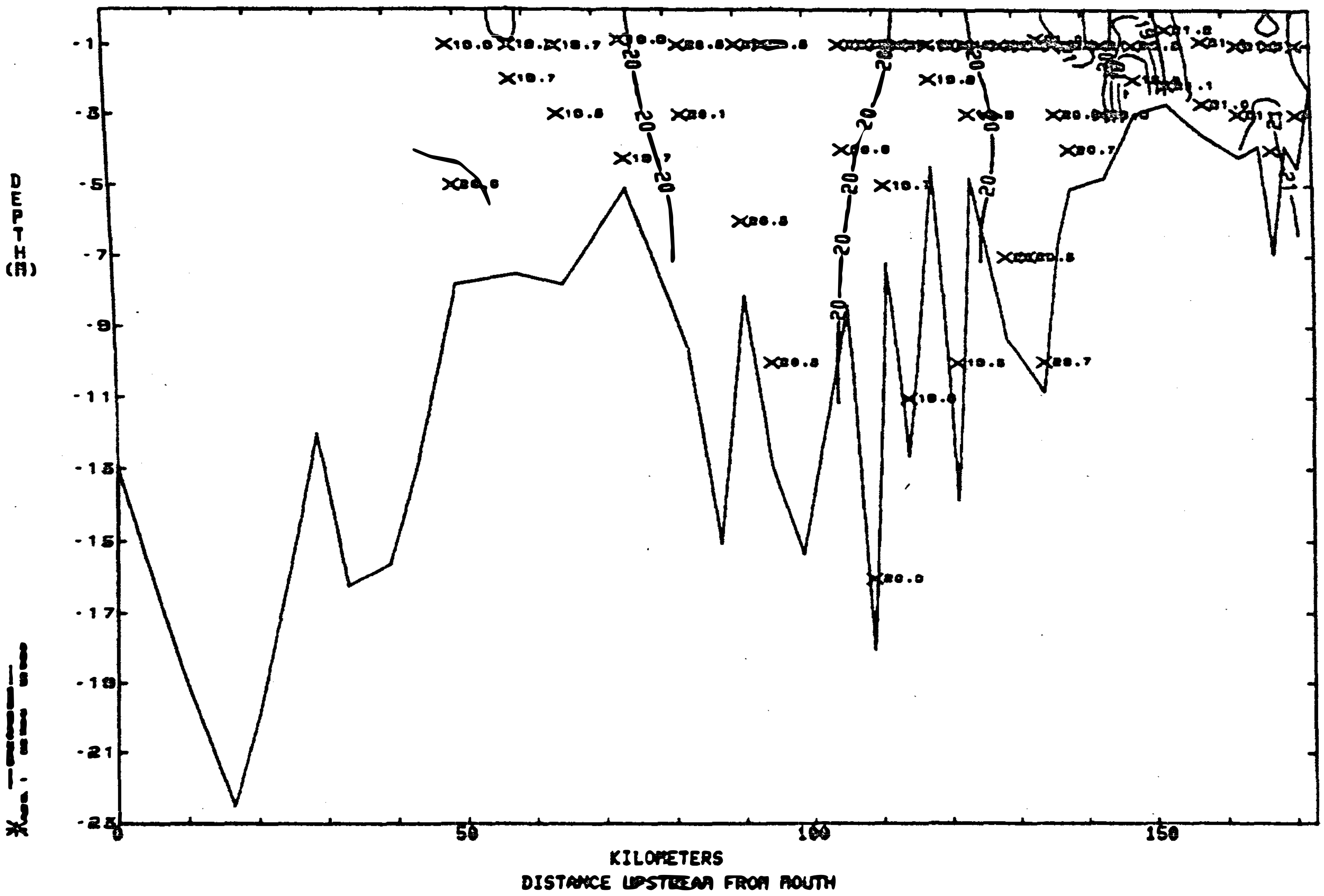
B. Temperature (^{o}C)

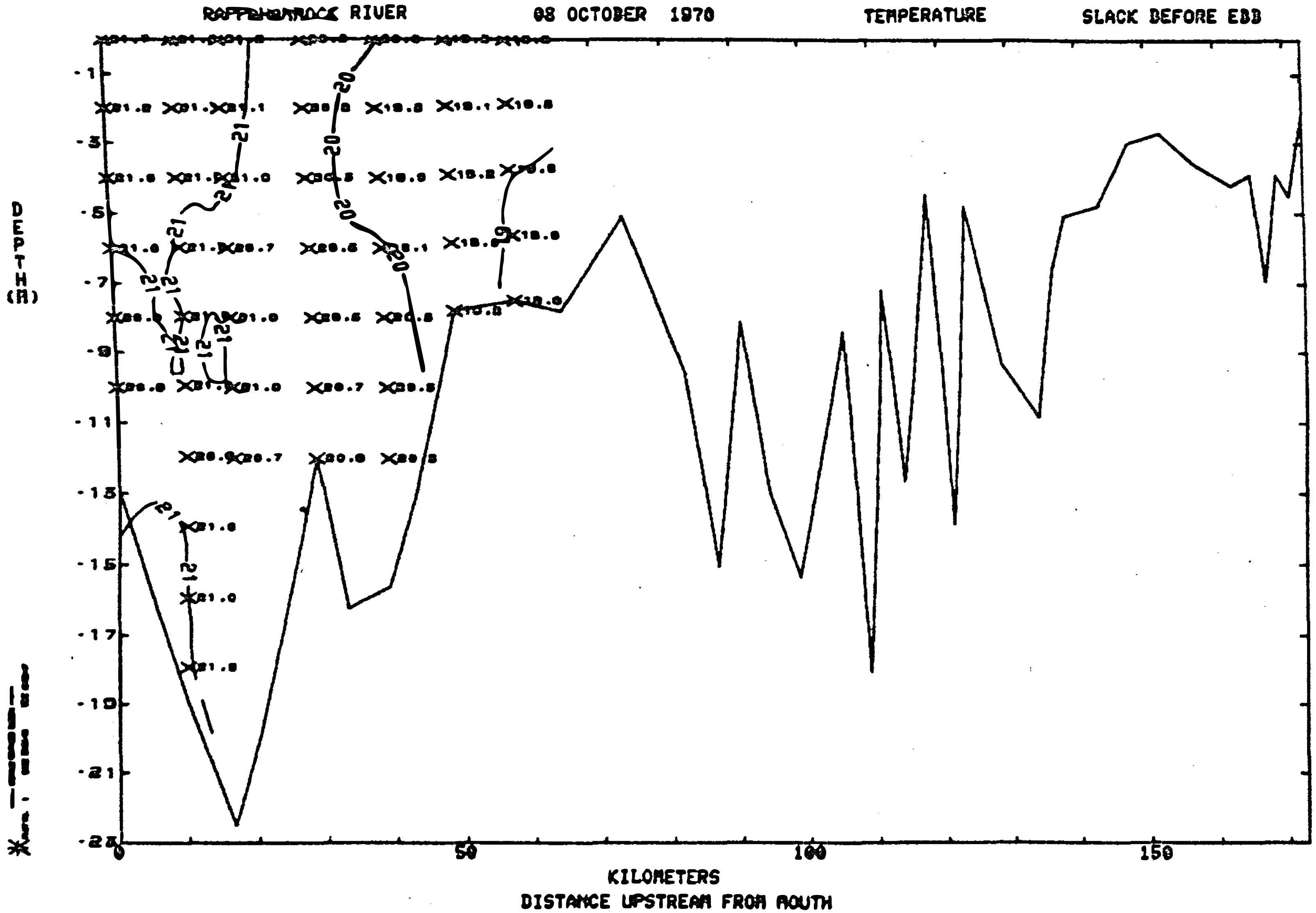


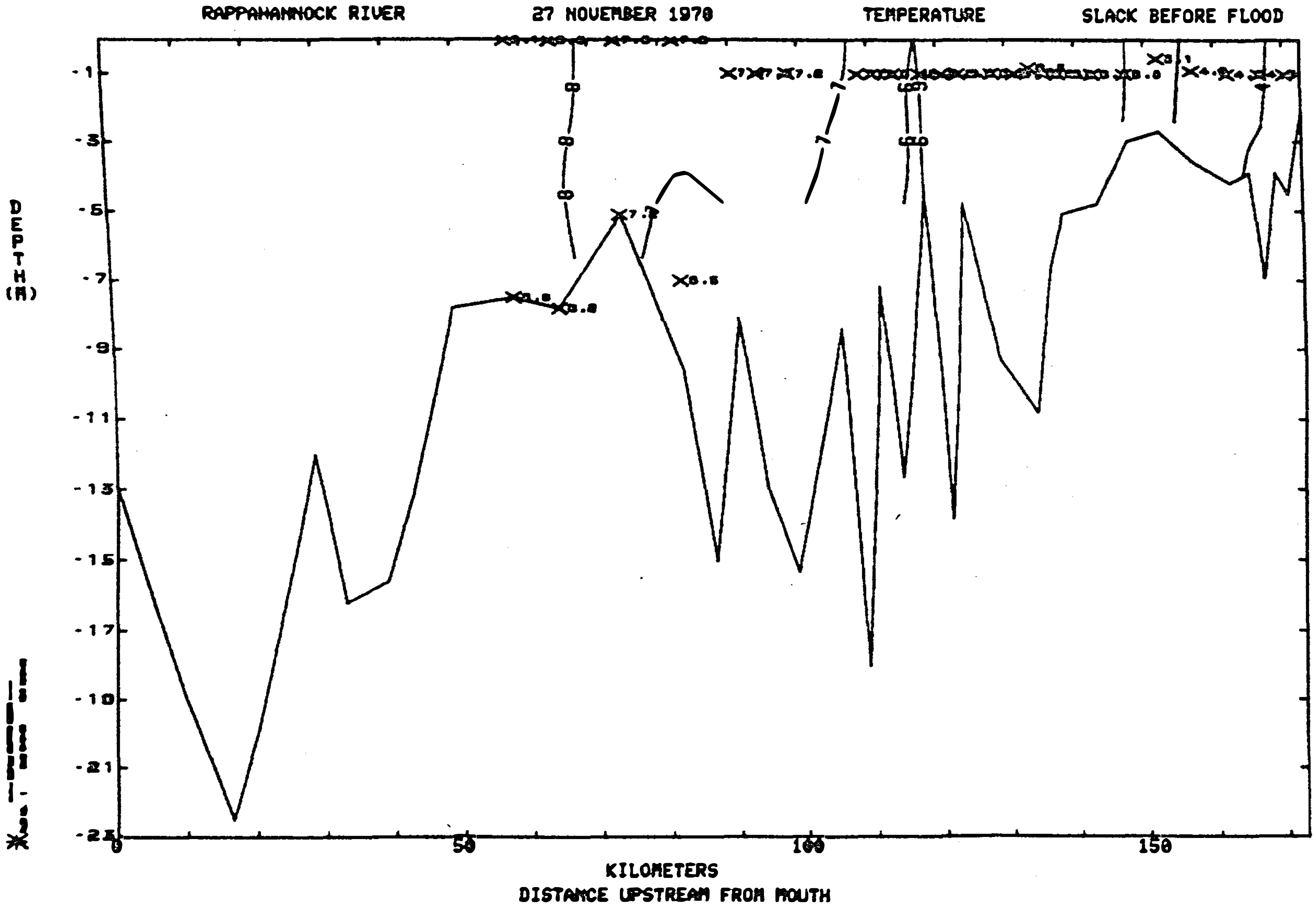
RAPPAHANNOCK RIVER
18 AUGUST 1970
TEMPERATURE
SLACK BEFORE EBB
DEPTH (M)
KILOMETERS
DISTANCE UPSTREAM FROM MOUTH

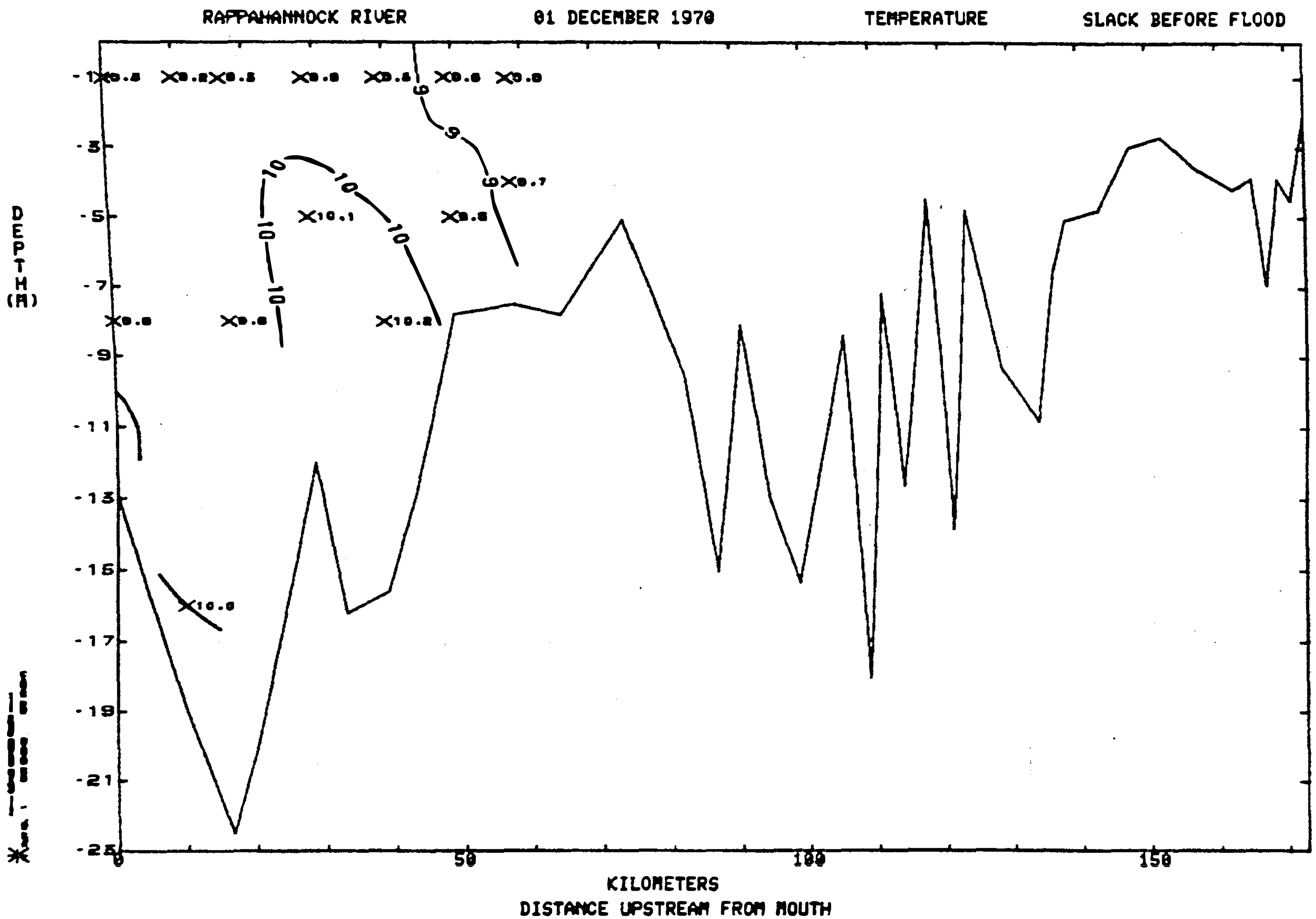

RAPPAHANNOCK RIVER
06 OCTOBER 1970
TEMPERATURE
SLACK BEFORE FLOOD
DEPTH (M)
KILOMETERS
DISTANCE UPSTREAM FROM MOUTH

RAPPAHANNOCK RIVER 06 OCTOBER 1978 TEMPERATURE SLACK BEFORE FLOOD

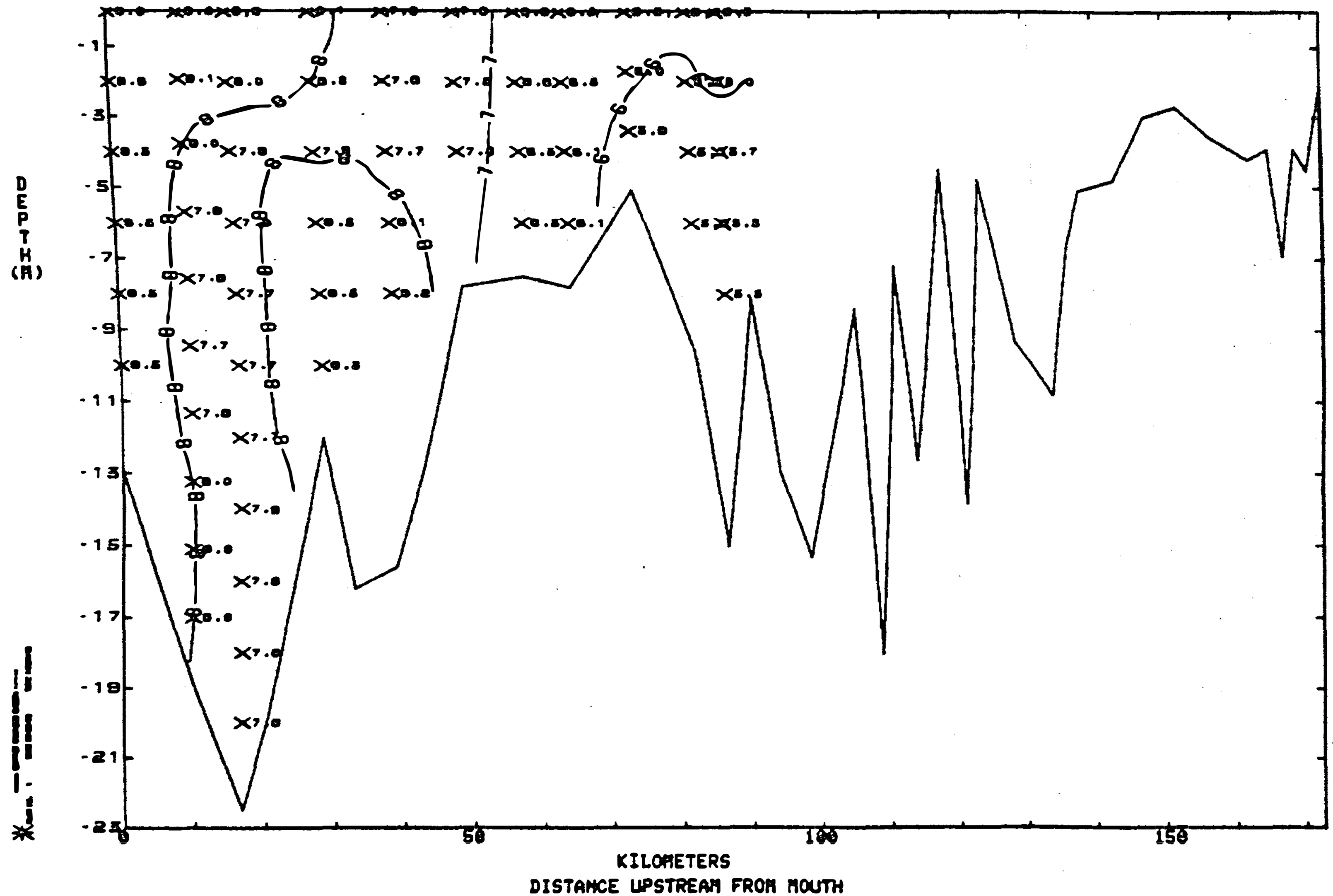


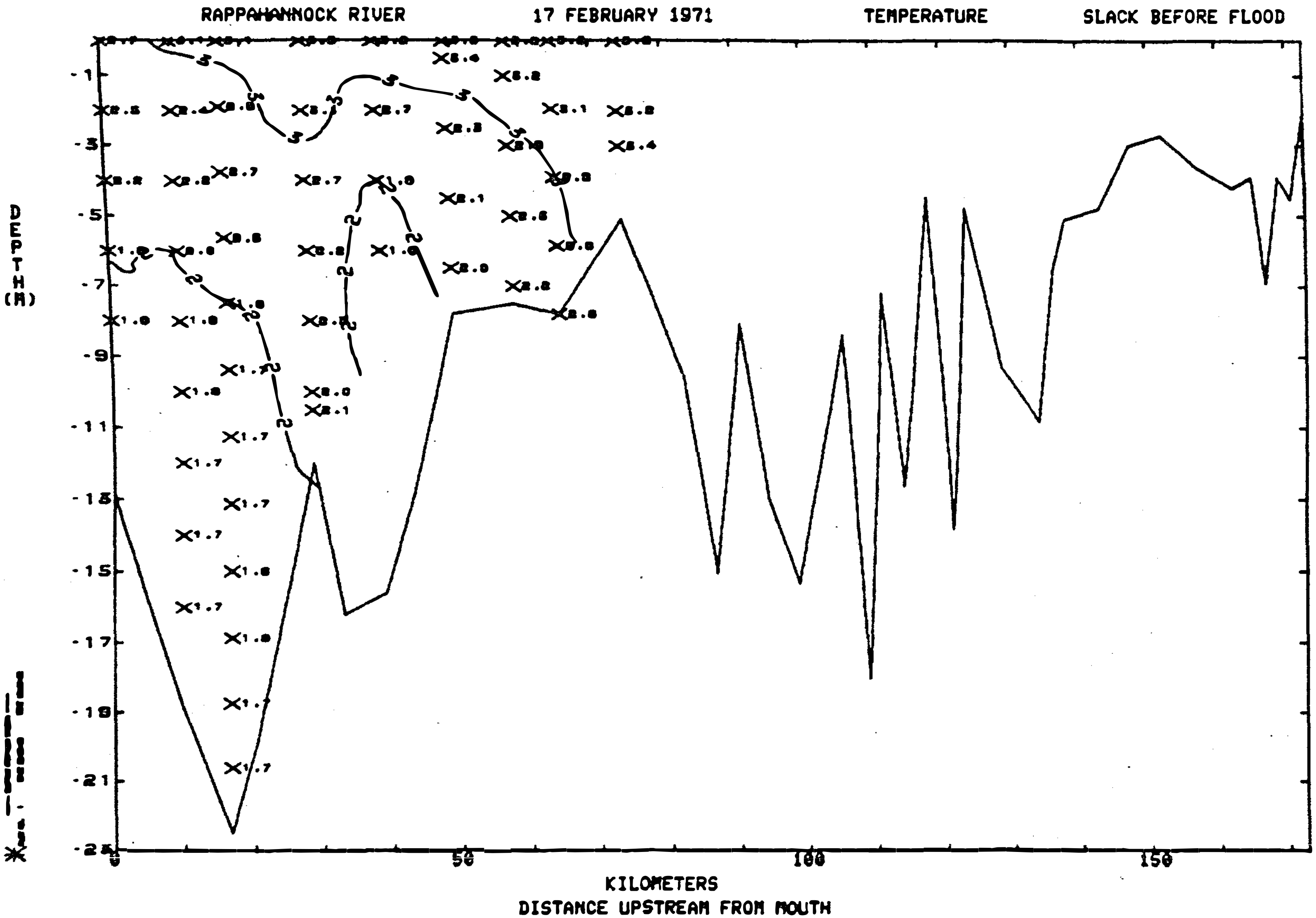

RAPPAHANNOCK RIVER
08 OCTOBER 1970
TEMPERATURE
SLACK BEFORE EBB
DEPTH (M)
KILOMETERS
DISTANCE UPSTREAM FROM MOUTH


RAPPAHANNOCK RIVER
27 NOVEMBER 1978
TEMPERATURE
SLACK BEFORE FLOOD
DEPTH (M)
-1
-3
-5
-7
-9
-11
-13
-15
-17
-19
-21
-23
0
50
100
150
KILOMETERS
DISTANCE UPSTREAM FROM MOUTH

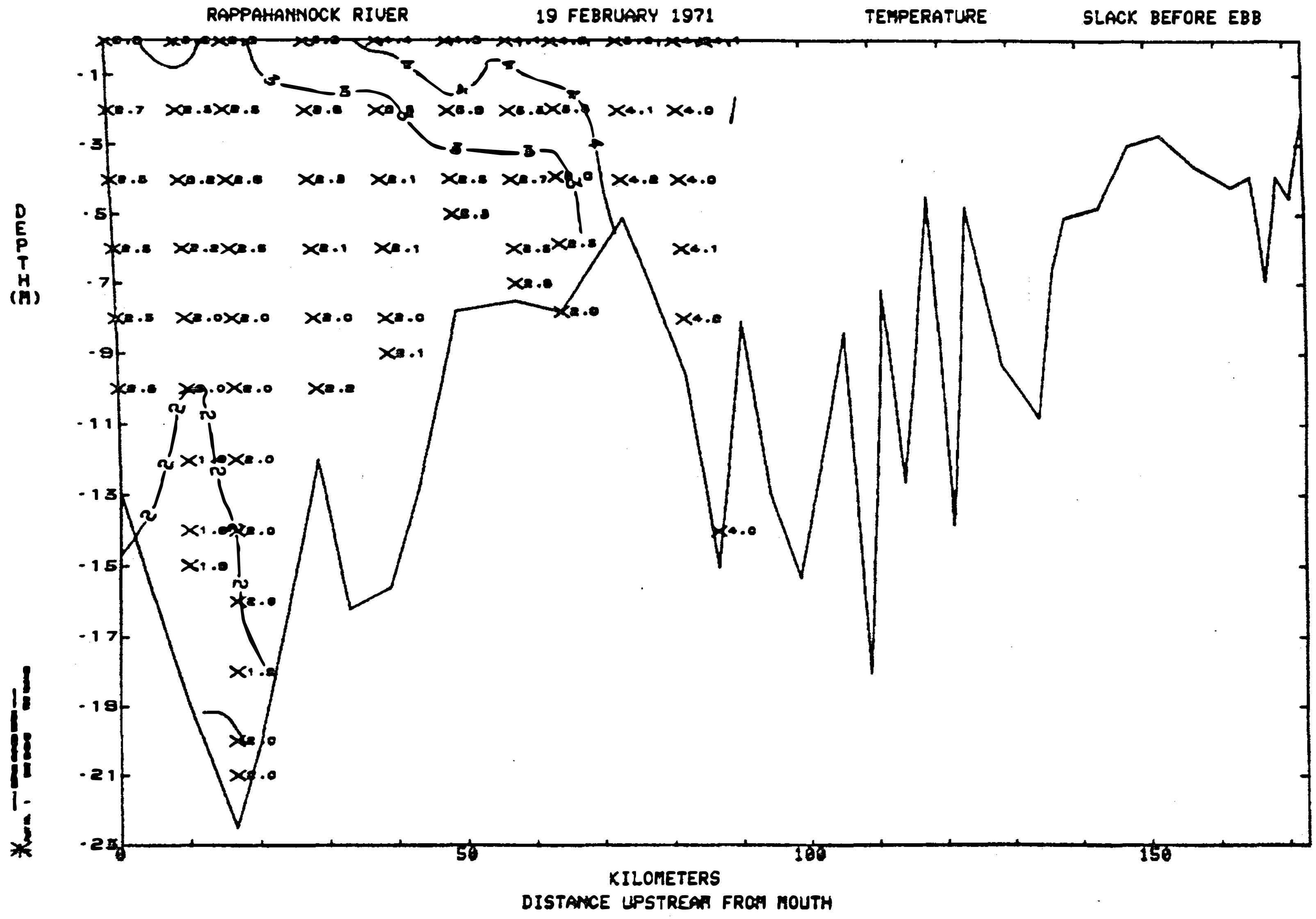

RAPPAHANNOCK RIVER
01 DECEMBER 1970
TEMPERATURE
SLACK BEFORE FLOOD
DEPTH (M)
KILOMETERS
DISTANCE UPSTREAM FROM MOUTH

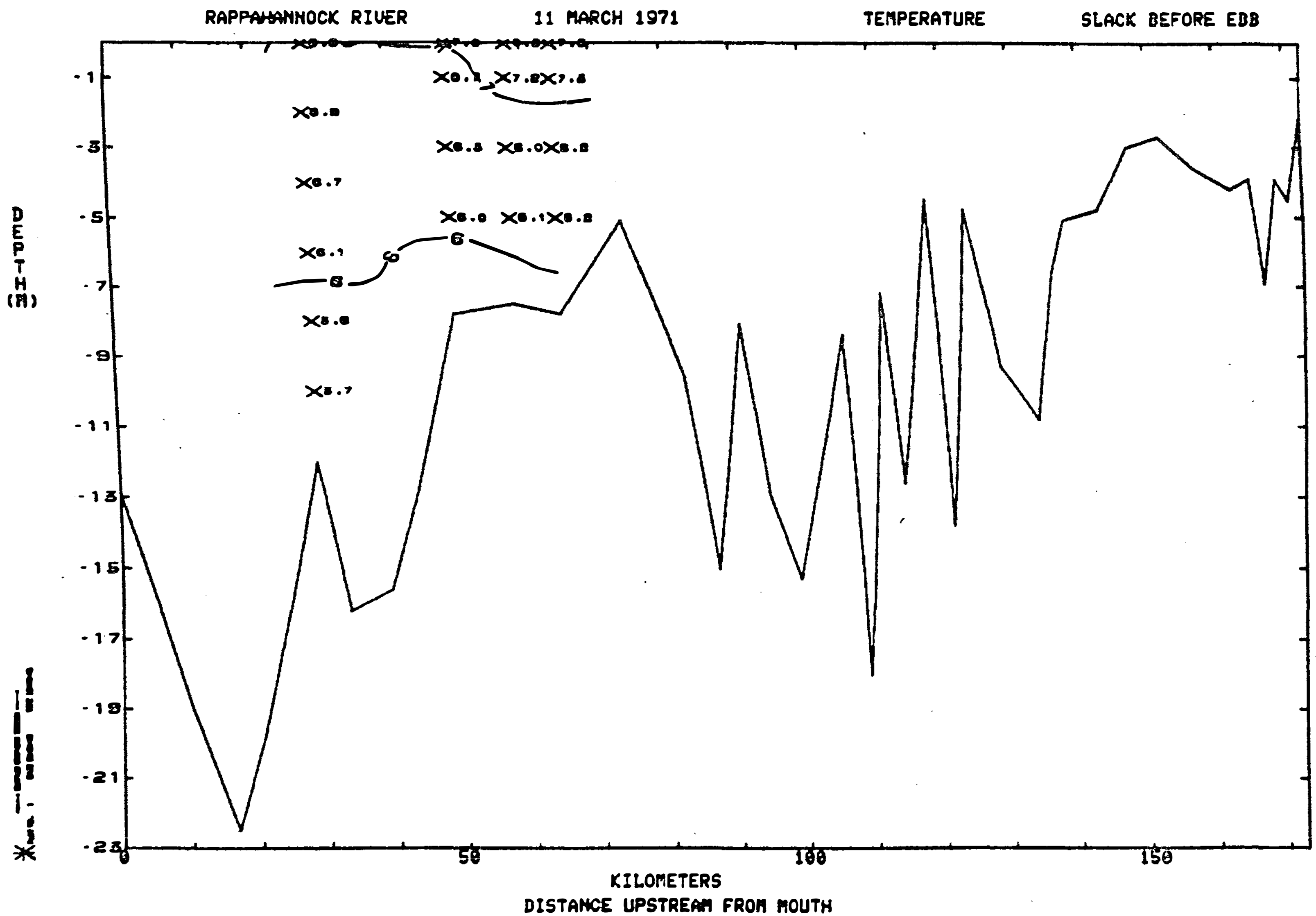
RAPPAHANNOCK RIVER 10 DECEMBER 1970 TEMPERATURE SLACK BEFORE EBB

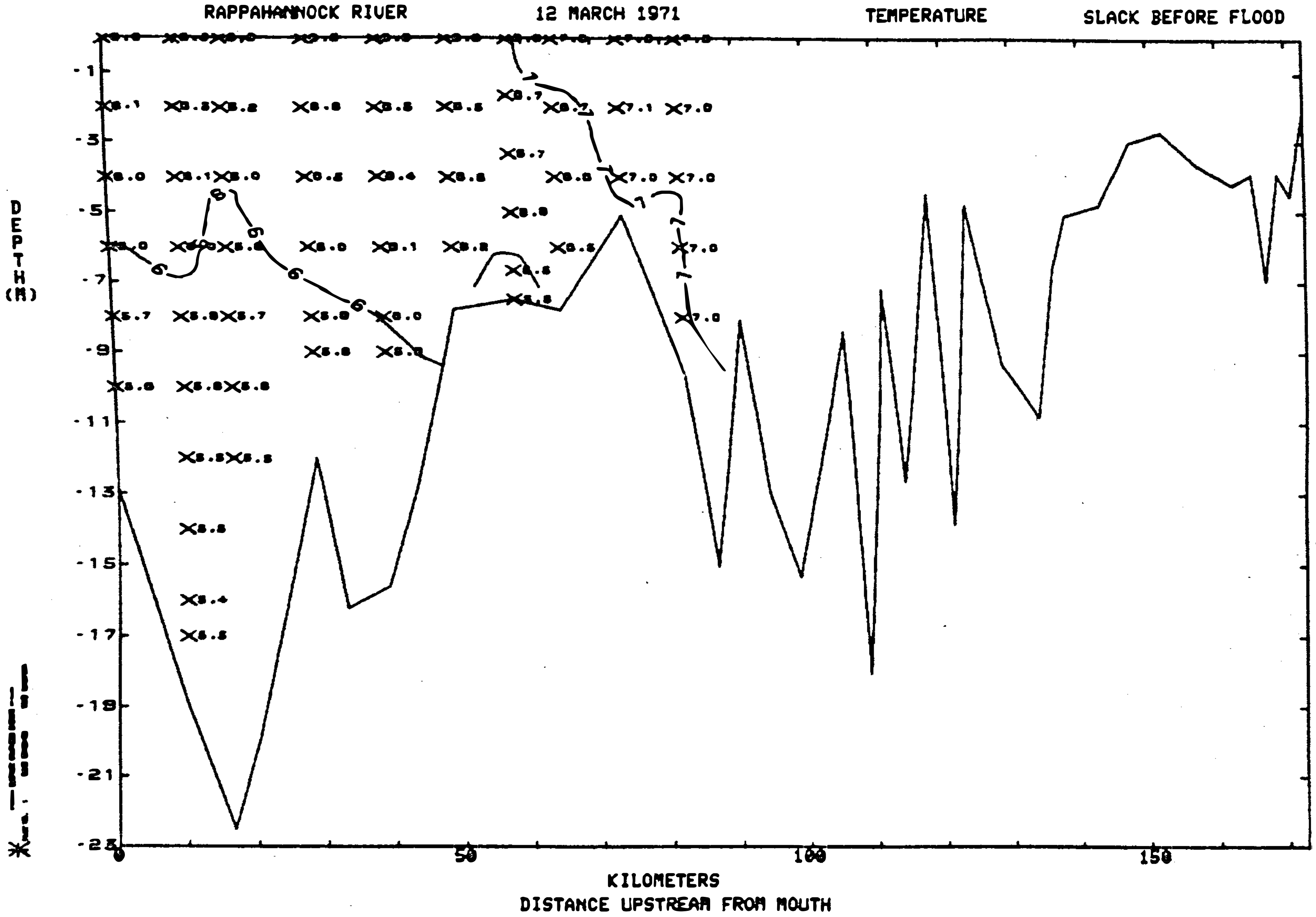


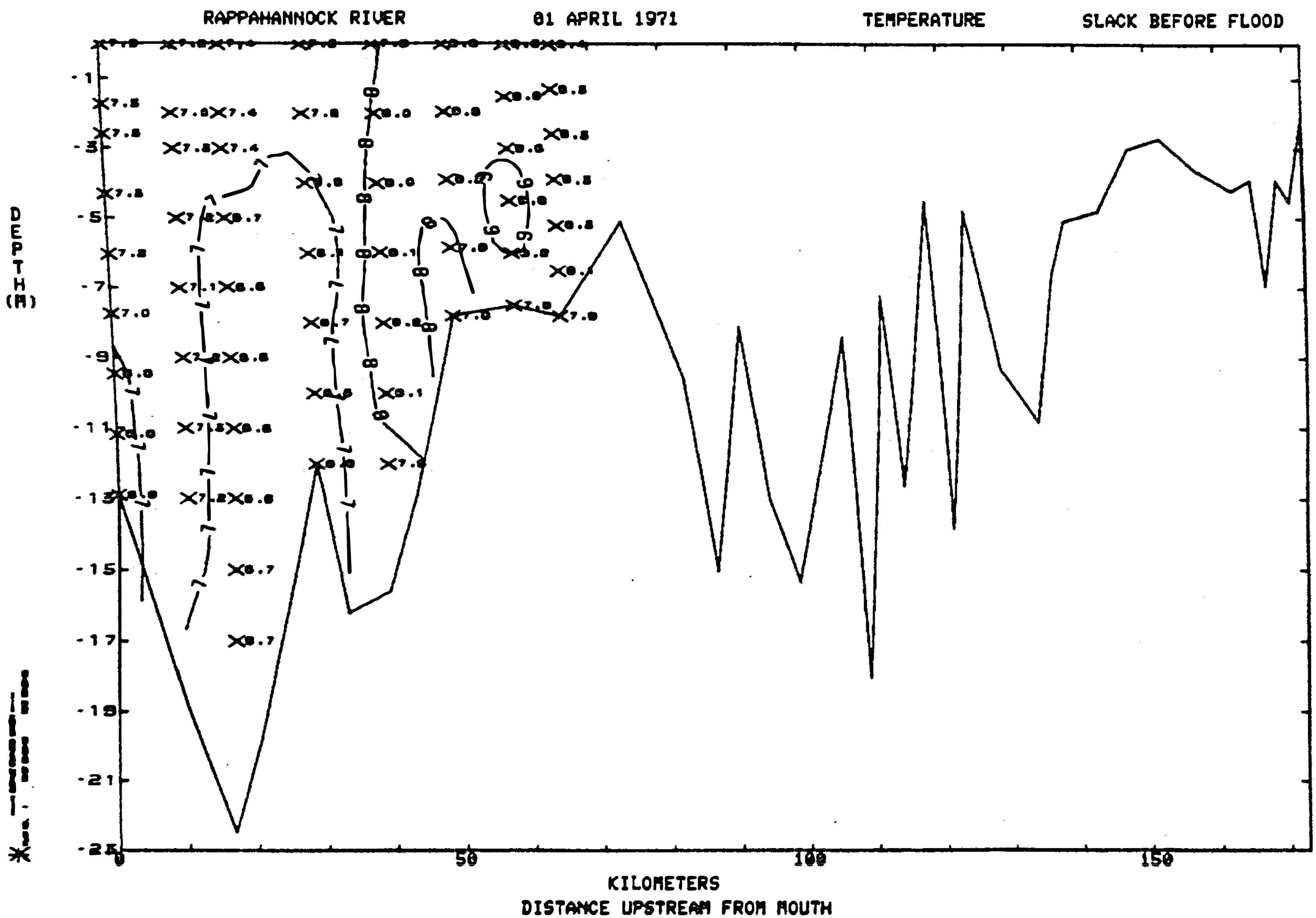


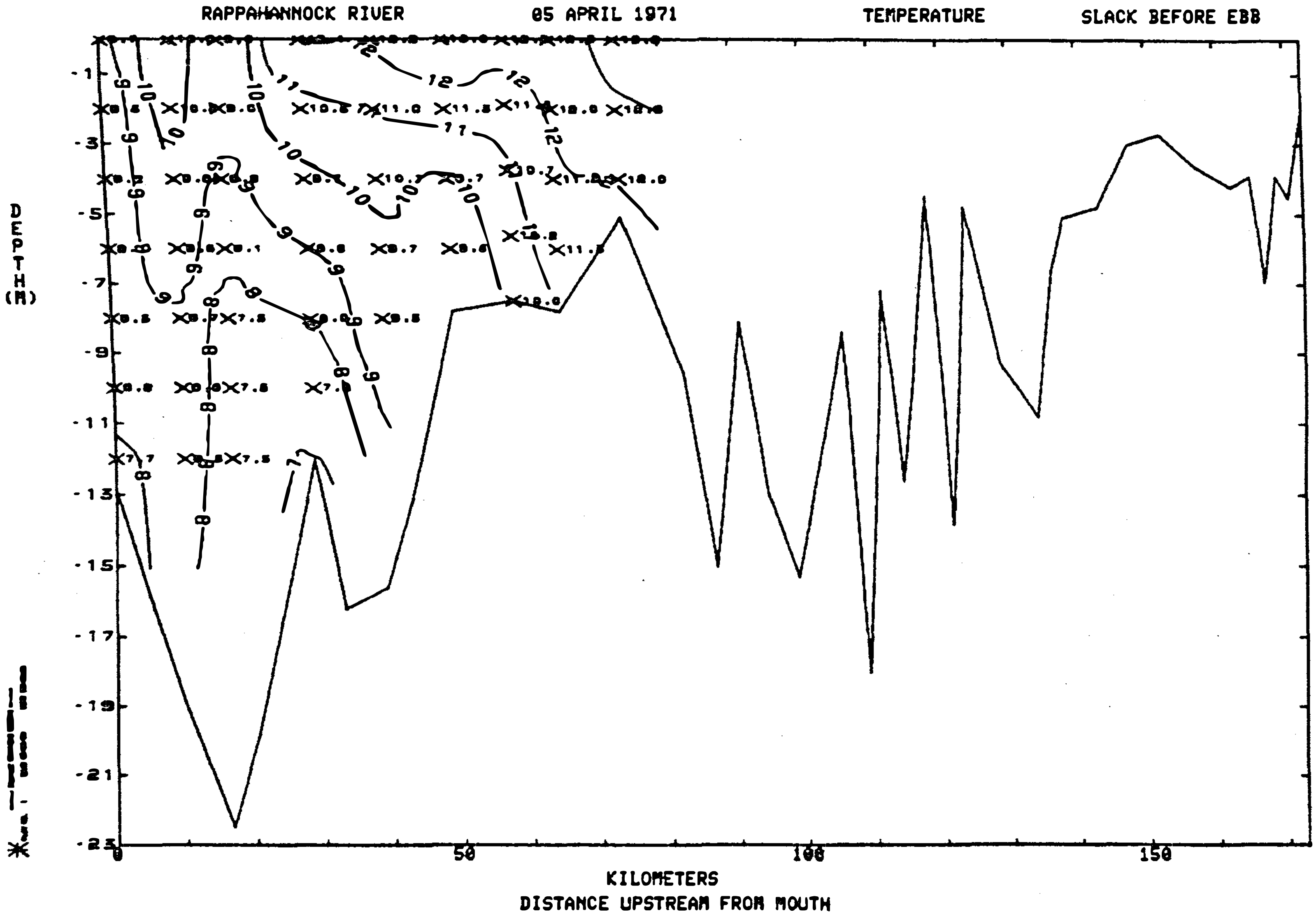
RAPPAHANNOCK RIVER
17 FEBRUARY 1971
TEMPERATURE
SLACK BEFORE FLOOD
DEPTH (M)
-1
-3
-5
-7
-9
-11
-15
-17
-21
0
50
100
150
KILOMETERS
DISTANCE UPSTREAM FROM MOUTH

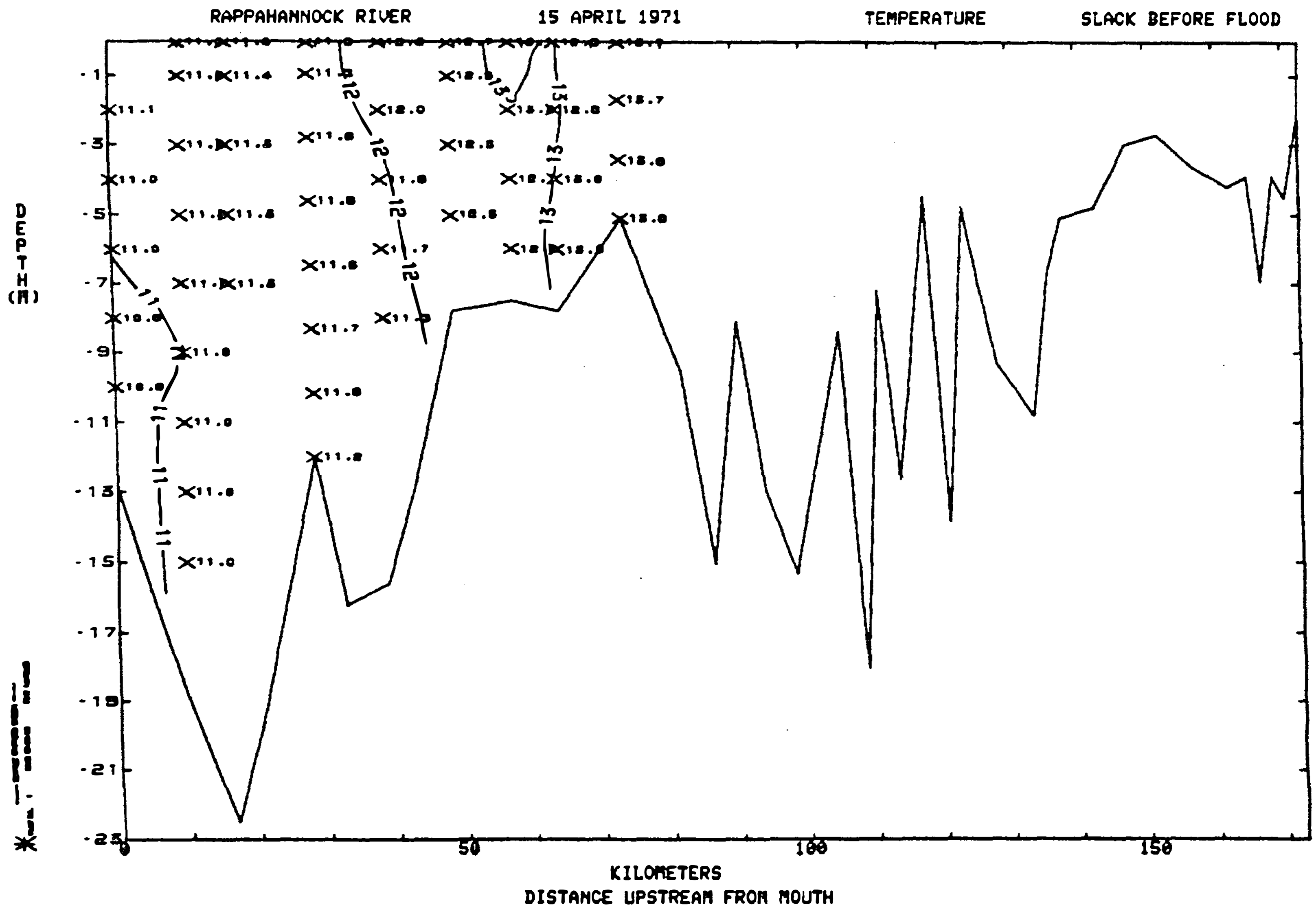

RAPPAHANNOCK RIVER
19 FEBRUARY 1971
TEMPERATURE
SLACK BEFORE EBB
DEPTH (M)
KILOMETERS
DISTANCE UPSTREAM FROM MOUTH


RAPPAHANNOCK RIVER
11 MARCH 1971
TEMPERATURE
SLACK BEFORE EBB
DEPTH (M)
-1
-3
-5
-7
-9
-11
-13
-15
-17
-19
-21
-23
0
50
100
150
KILOMETERS
DISTANCE UPSTREAM FROM MOUTH

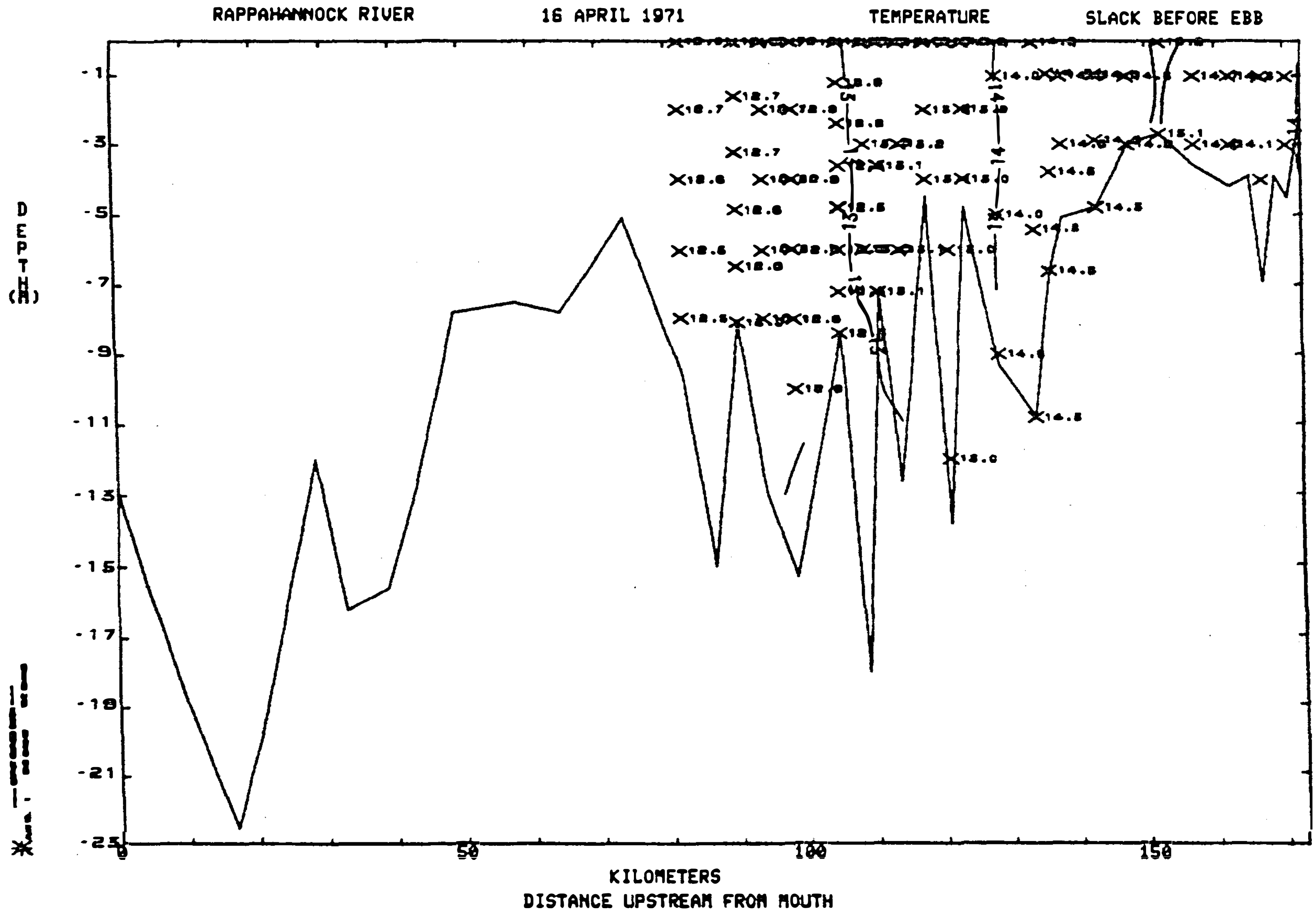

RAPPAHANNOCK RIVER
12 MARCH 1971
TEMPERATURE
SLACK BEFORE FLOOD
DEPTH (M)
KILOMETERS
DISTANCE UPSTREAM FROM MOUTH


RAPPAHANNOCK RIVER
01 APRIL 1971
TEMPERATURE
SLACK BEFORE FLOOD
DEPTH (M)
KILOMETERS
DISTANCE UPSTREAM FROM MOUTH

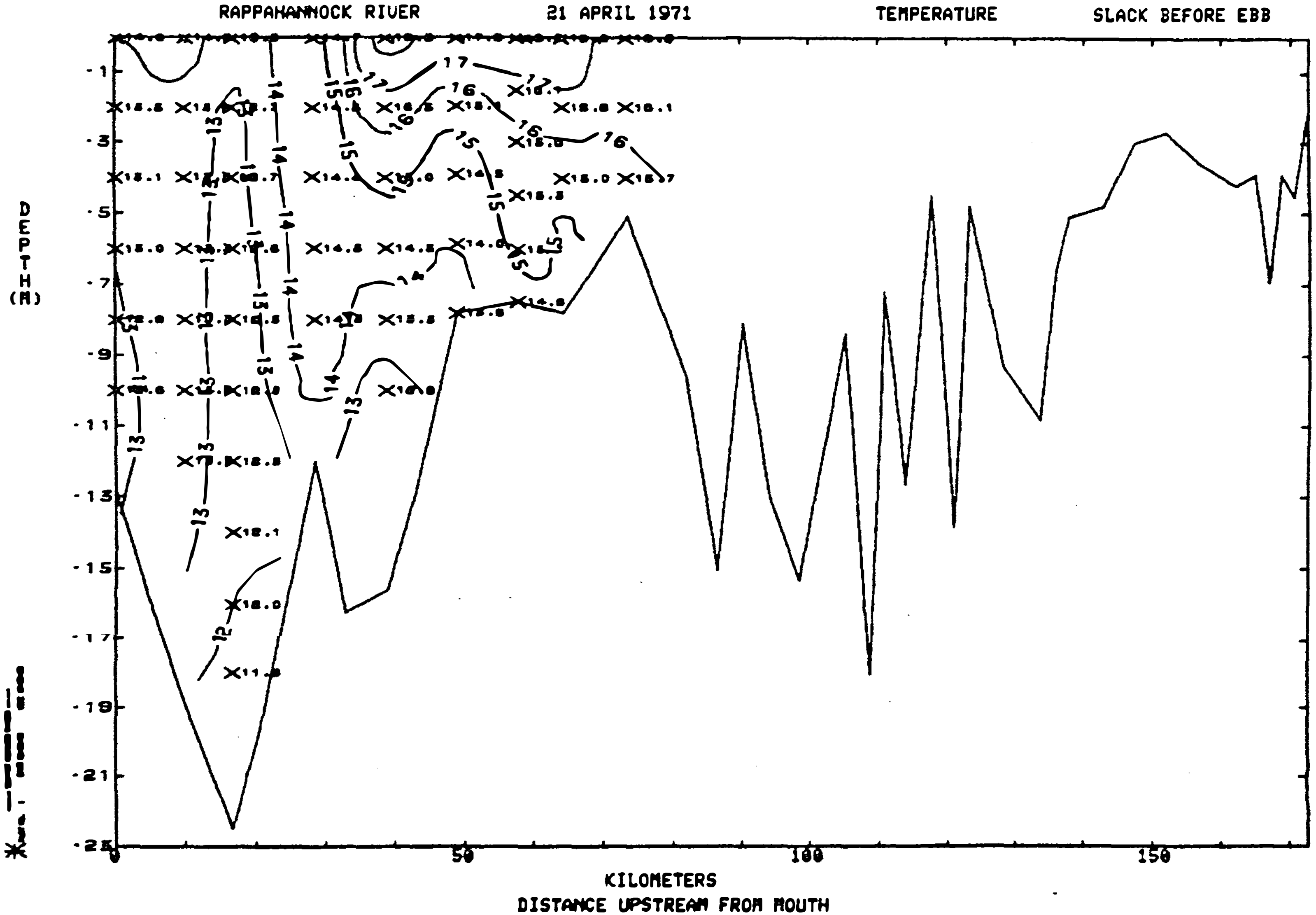

RAPPAHANNOCK RIVER
05 APRIL 1971
TEMPERATURE
SLACK BEFORE EBB
DEPTH (M)
KILOMETERS
DISTANCE UPSTREAM FROM MOUTH

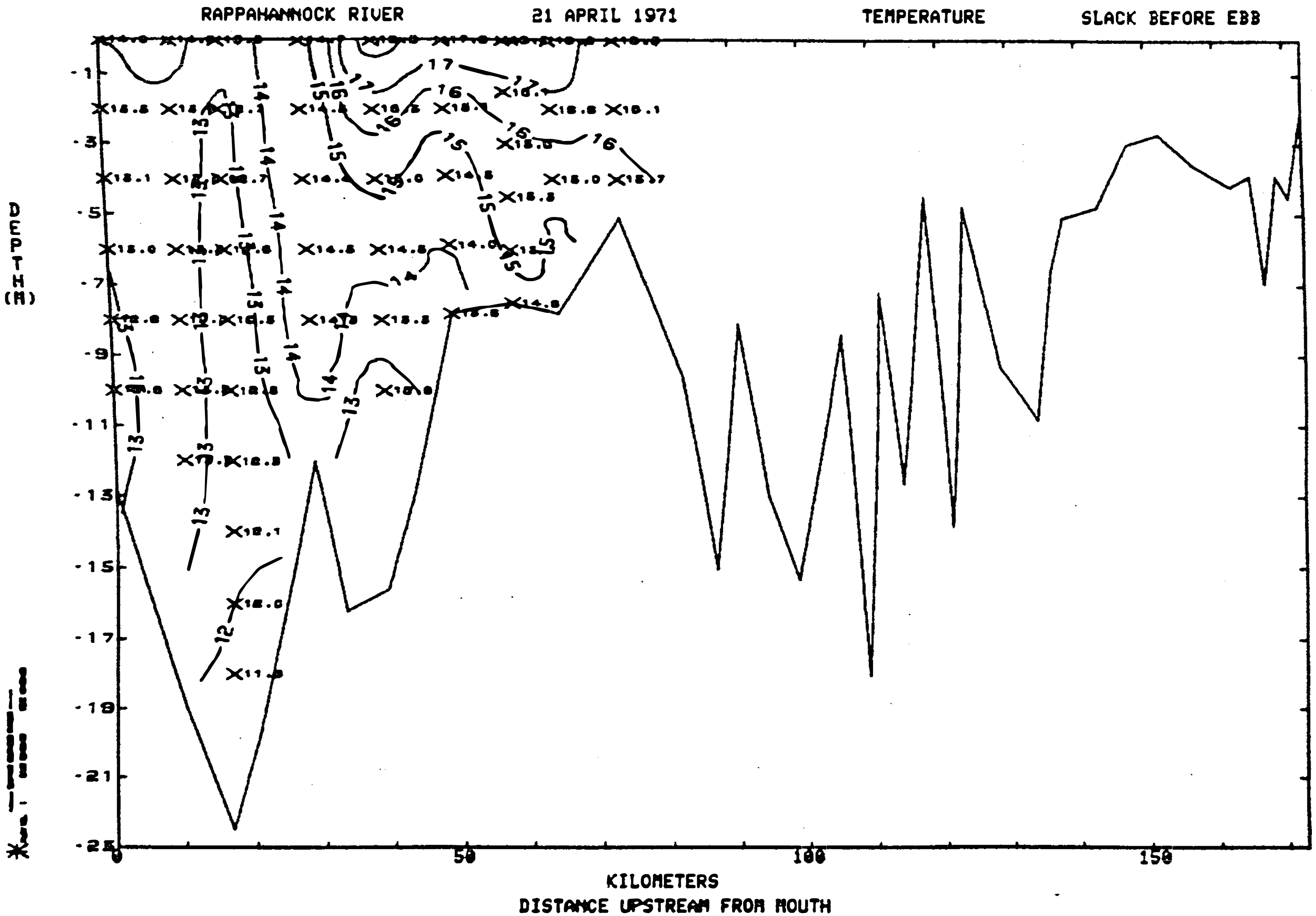


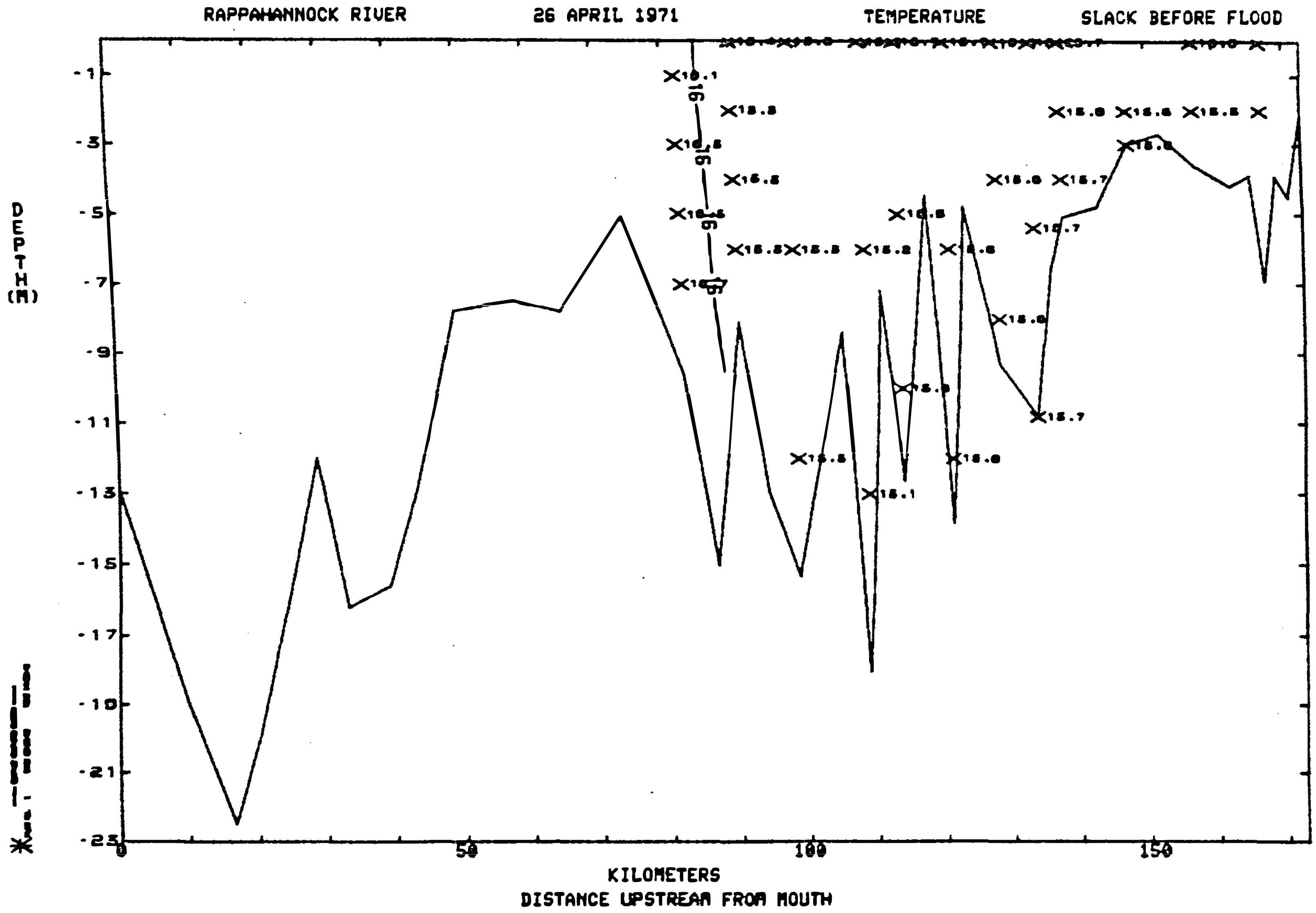
RAPPAHANNOCK RIVER
15 APRIL 1971
TEMPERATURE
SLACK BEFORE FLOOD
DEPTH (M)
KILOMETERS
DISTANCE UPSTREAM FROM MOUTH

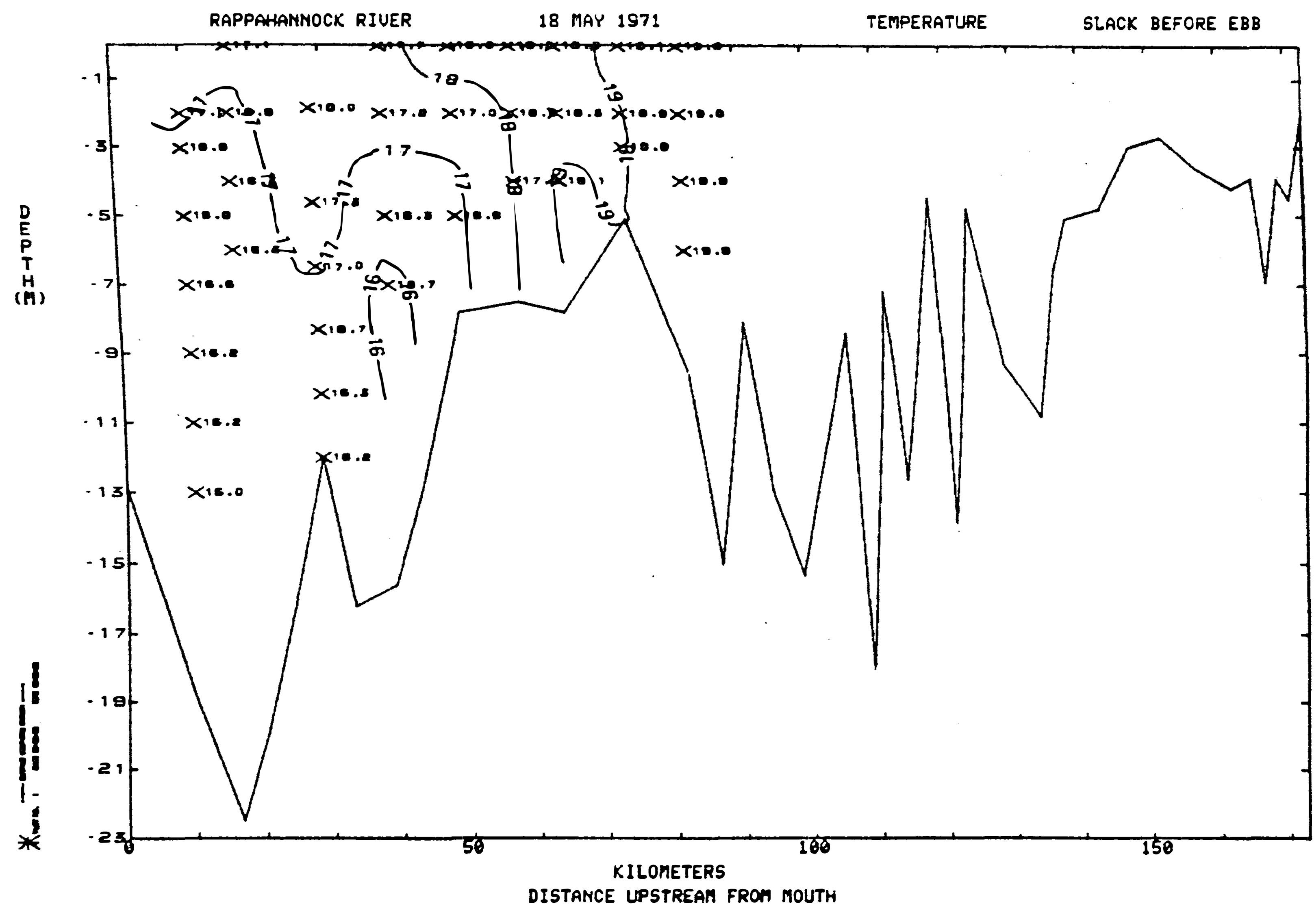


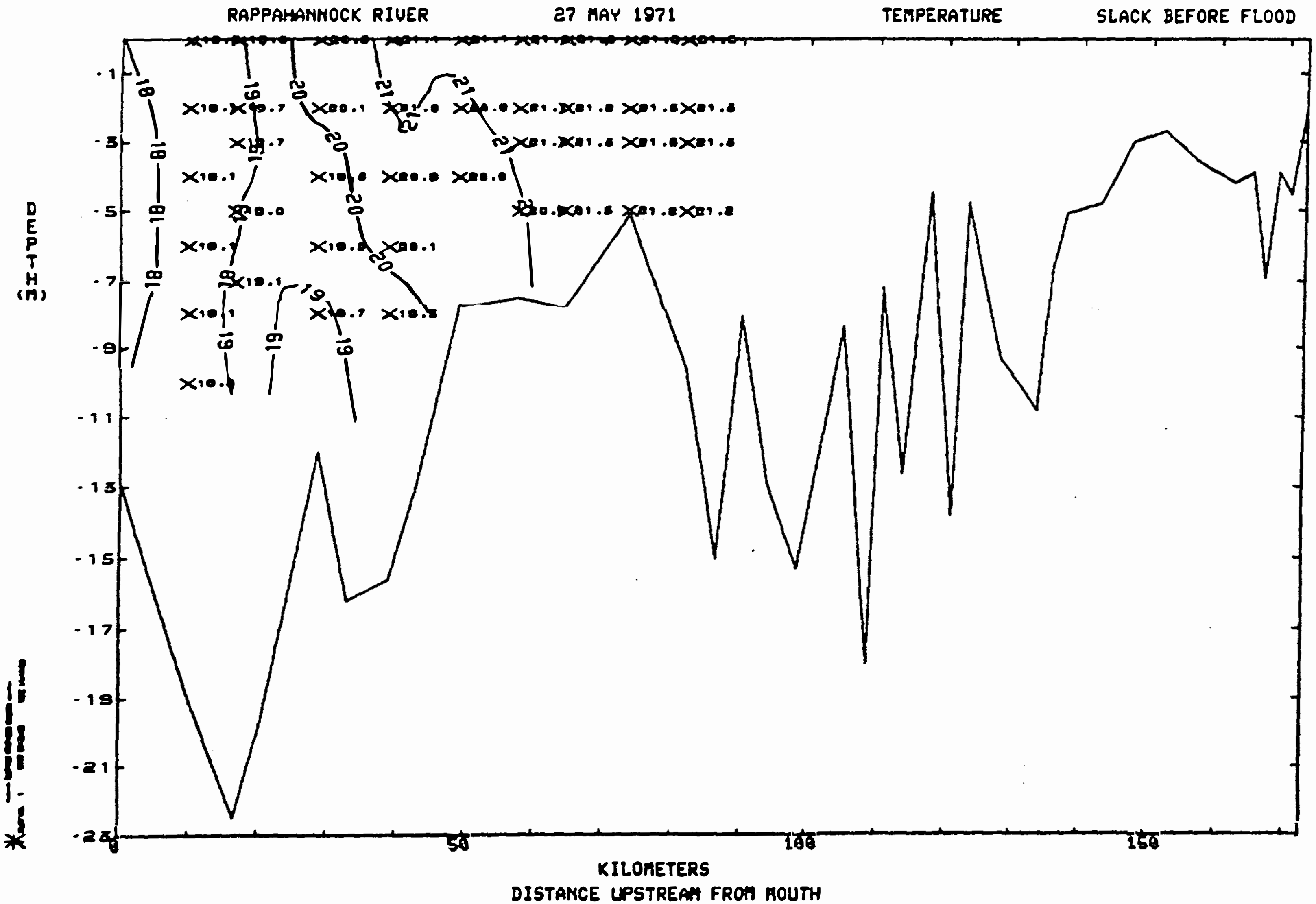
RAPPAHANNOCK RIVER
16 APRIL 1971
TEMPERATURE
SLACK BEFORE EBB
DEPTH (M)
KILOMETERS
DISTANCE UPSTREAM FROM MOUTH


RAPPAHANNOCK RIVER
21 APRIL 1971
TEMPERATURE
SLACK BEFORE EBB
DEPTH (M)
-1
-3
-5
-7
-9
-11
-13
-15
-17
-19
-21
-23
0
50
100
150
KILOMETERS
DISTANCE UPSTREAM FROM MOUTH

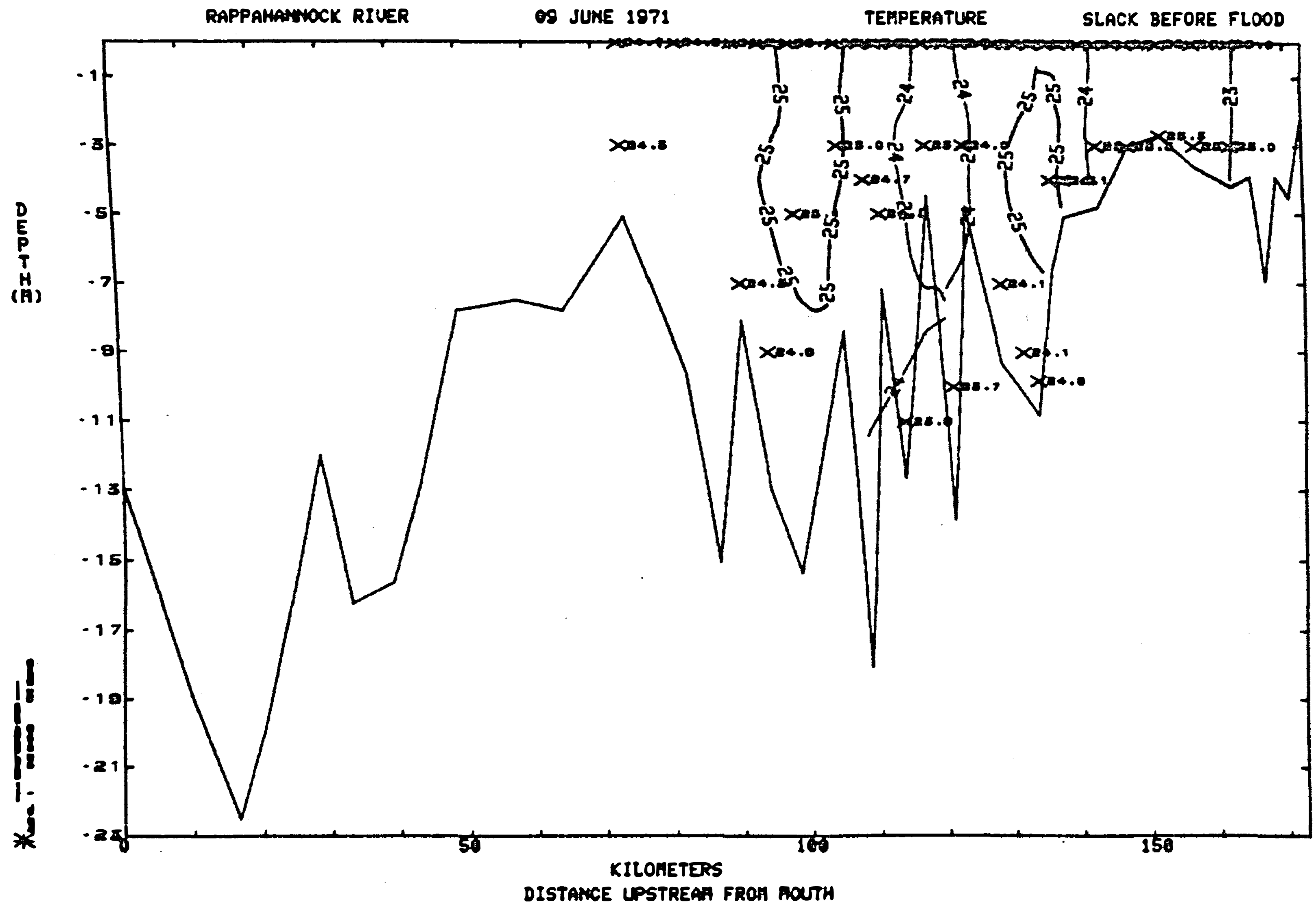

RAPPAHANNOCK RIVER
21 APRIL 1971
TEMPERATURE
SLACK BEFORE EBB
DEPTH (M)
KILOMETERS
DISTANCE UPSTREAM FROM MOUTH


RAPPAHANNOCK RIVER
26 APRIL 1971
TEMPERATURE
SLACK BEFORE FLOOD
DEPTH (M)
KILOMETERS
DISTANCE UPSTREAM FROM MOUTH

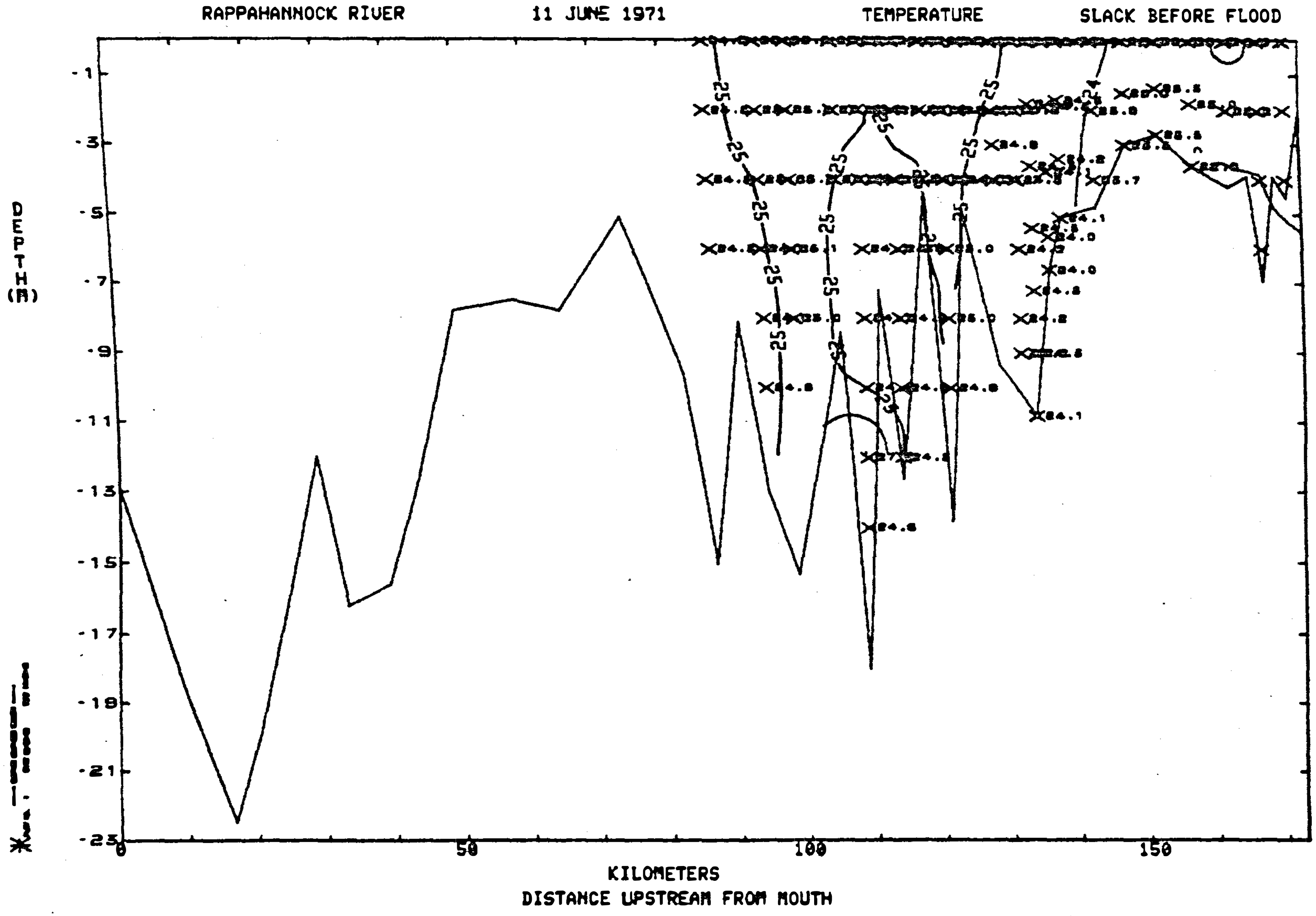

RAPPAHANNOCK RIVER
18 MAY 1971
TEMPERATURE
SLACK BEFORE EBB
DEPTH (M)
KILOMETERS
DISTANCE UPSTREAM FROM MOUTH



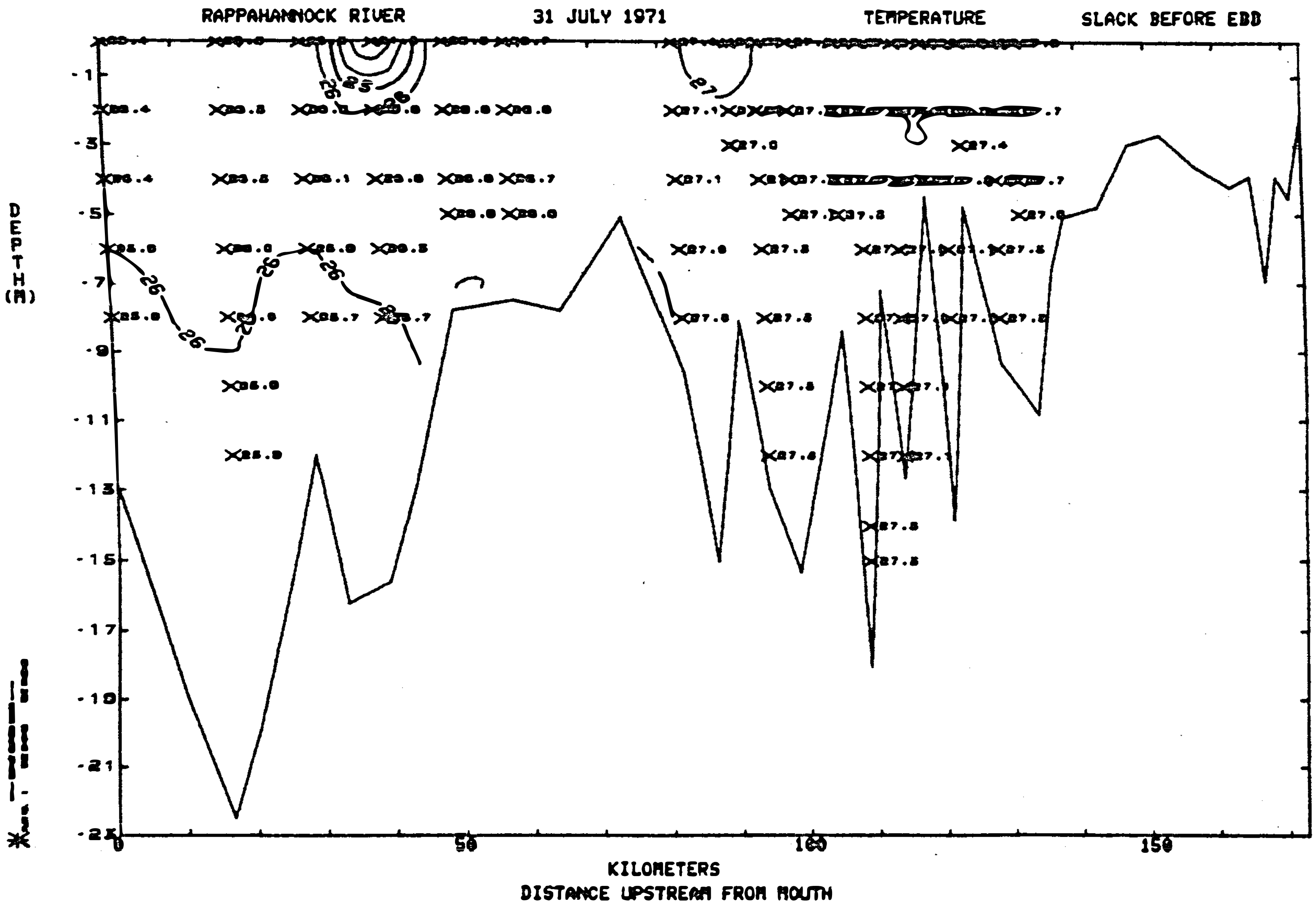
RAPPAHANNOCK RIVER
27 MAY 1971
TEMPERATURE
SLACK BEFORE FLOOD
DEPTH (M)
-1
-3
-5
-7
-9
-11
-13
-15
-17
-19
-21
-23
0
50
100
150
KILOMETERS
DISTANCE UPSTREAM FROM MOUTH



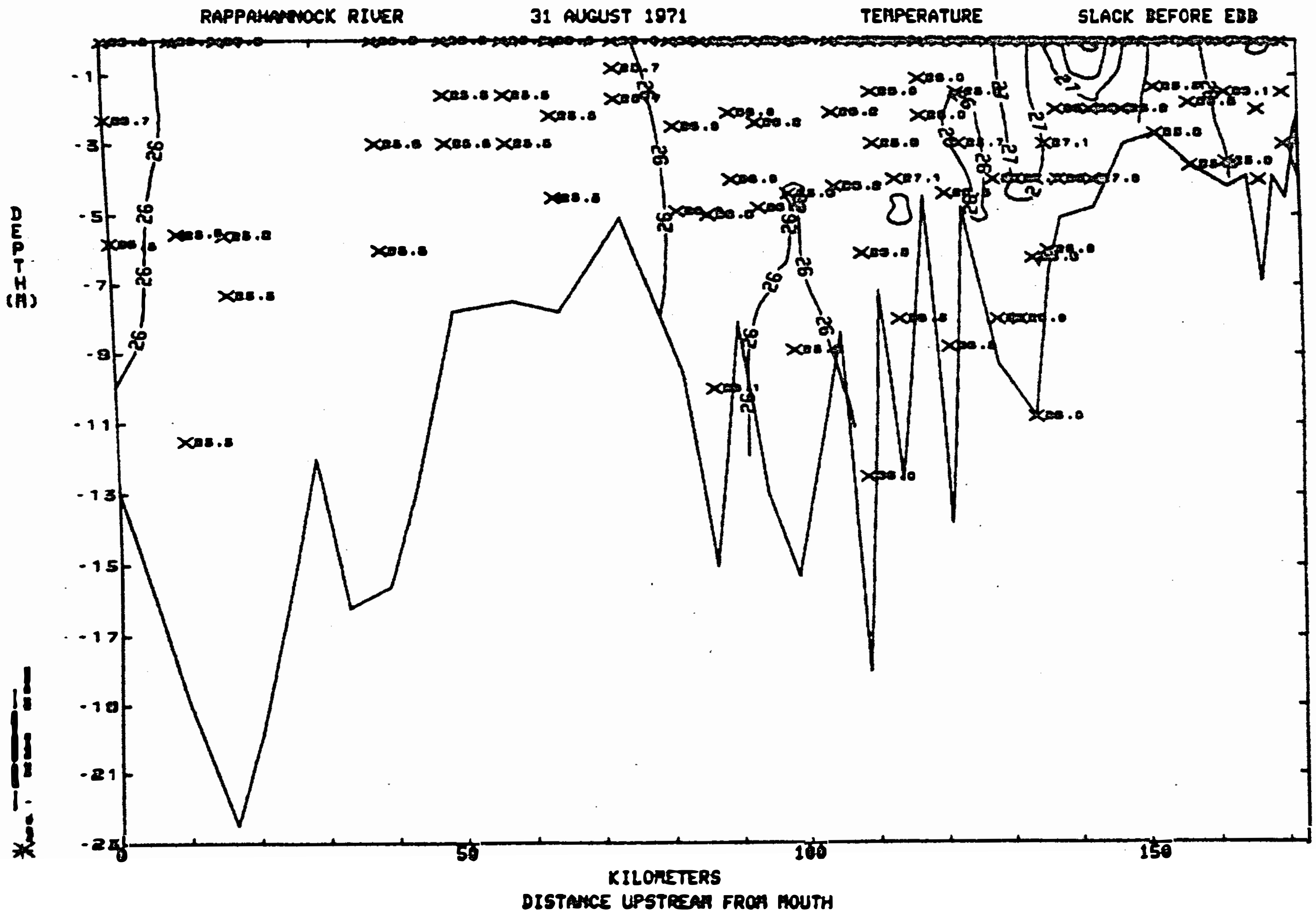
RAPPAHANNOCK RIVER
09 JUNE 1971
TEMPERATURE
SLACK BEFORE FLOOD
DEPTH (M)
-1
-3
-5
-7
-9
-11
-13
-15
-17
-19
-21
-23
0
50
100
150
KILOMETERS
DISTANCE UPSTREAM FROM MOUTH

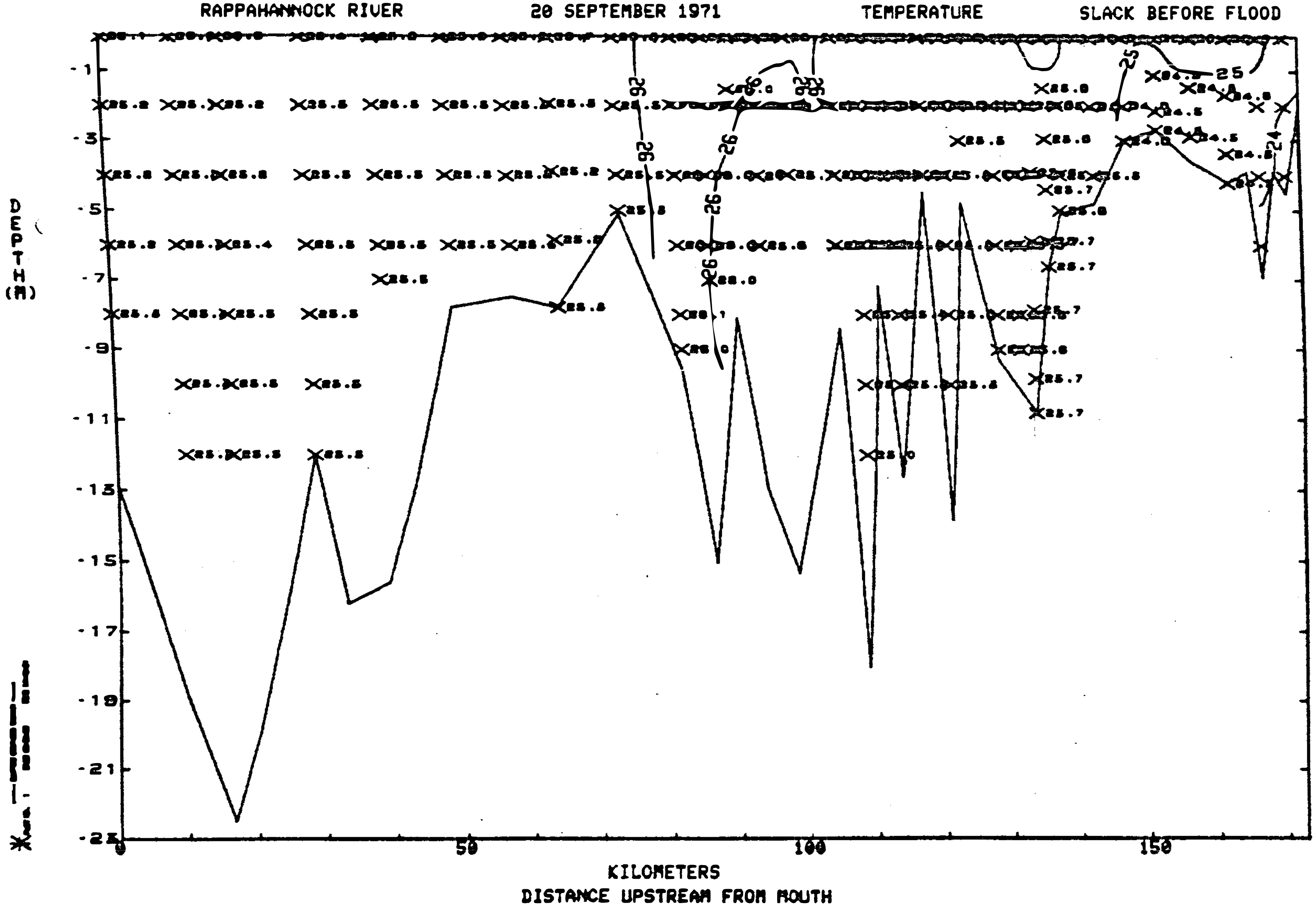


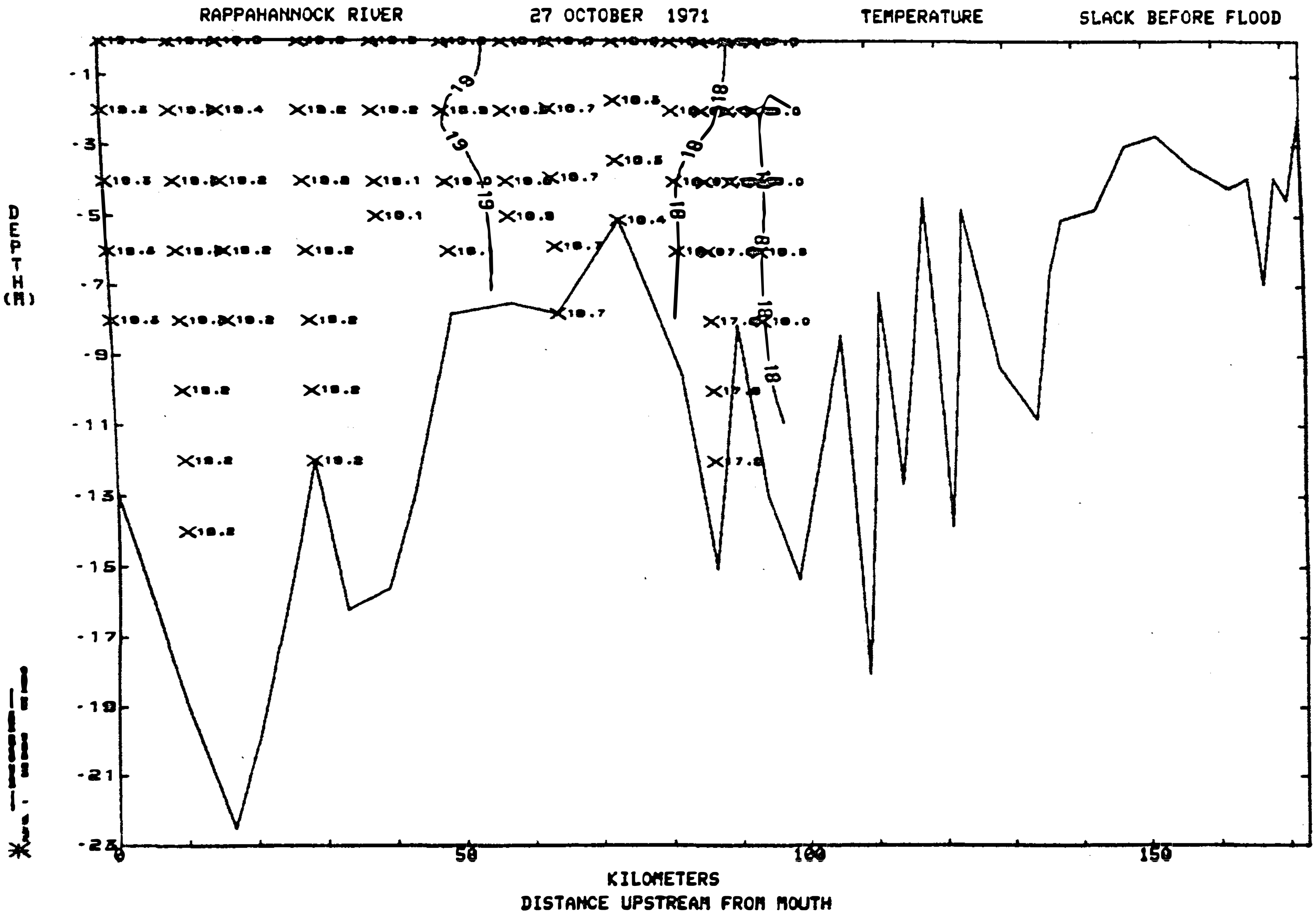
RAPPAHANNOCK RIVER
11 JUNE 1971
TEMPERATURE
SLACK BEFORE FLOOD
DEPTH (M)
-1
-3
-5
-7
-9
-11
-13
-15
-17
-19
-21
-23
0
50
100
150
KILOMETERS
DISTANCE UPSTREAM FROM MOUTH

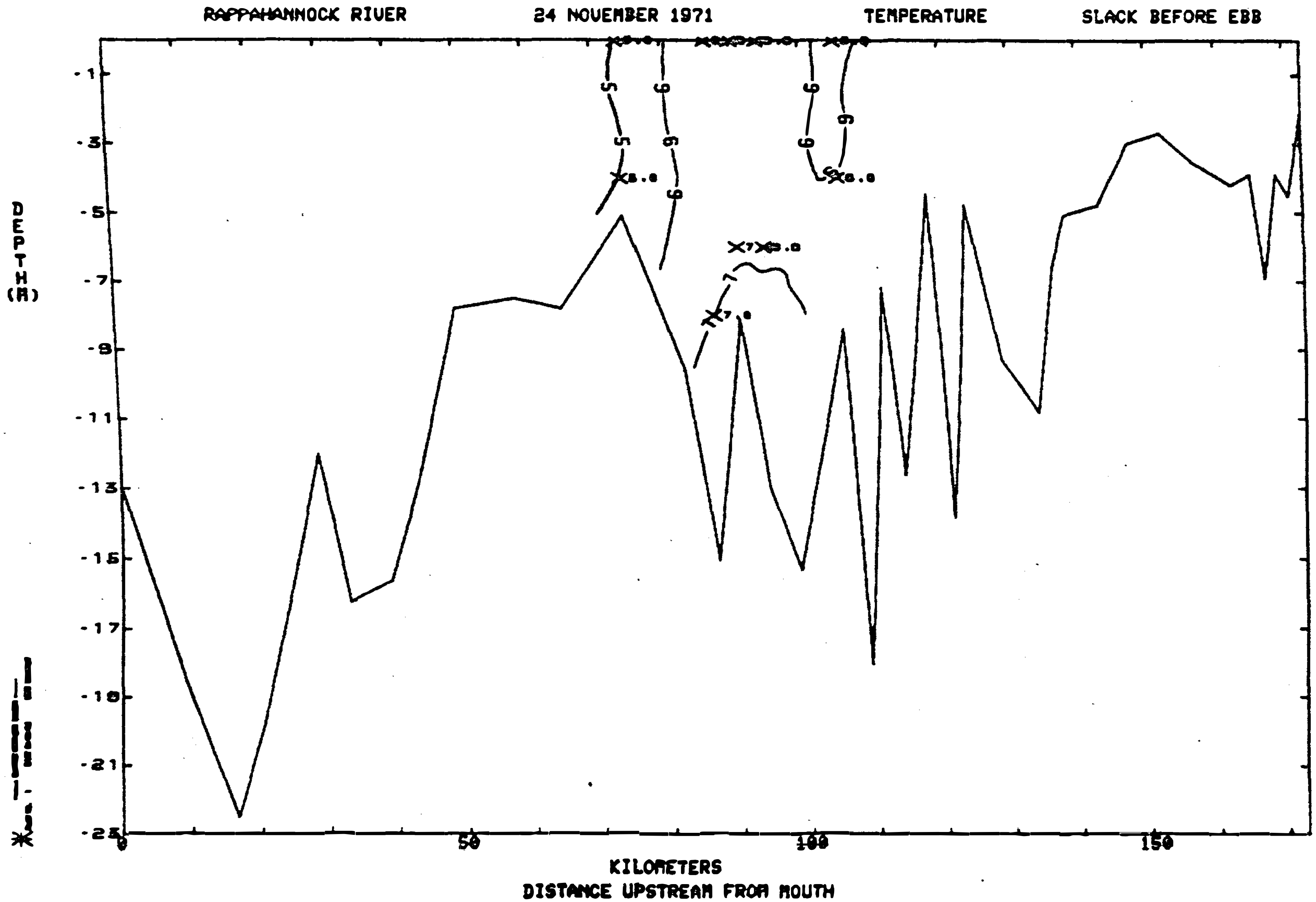


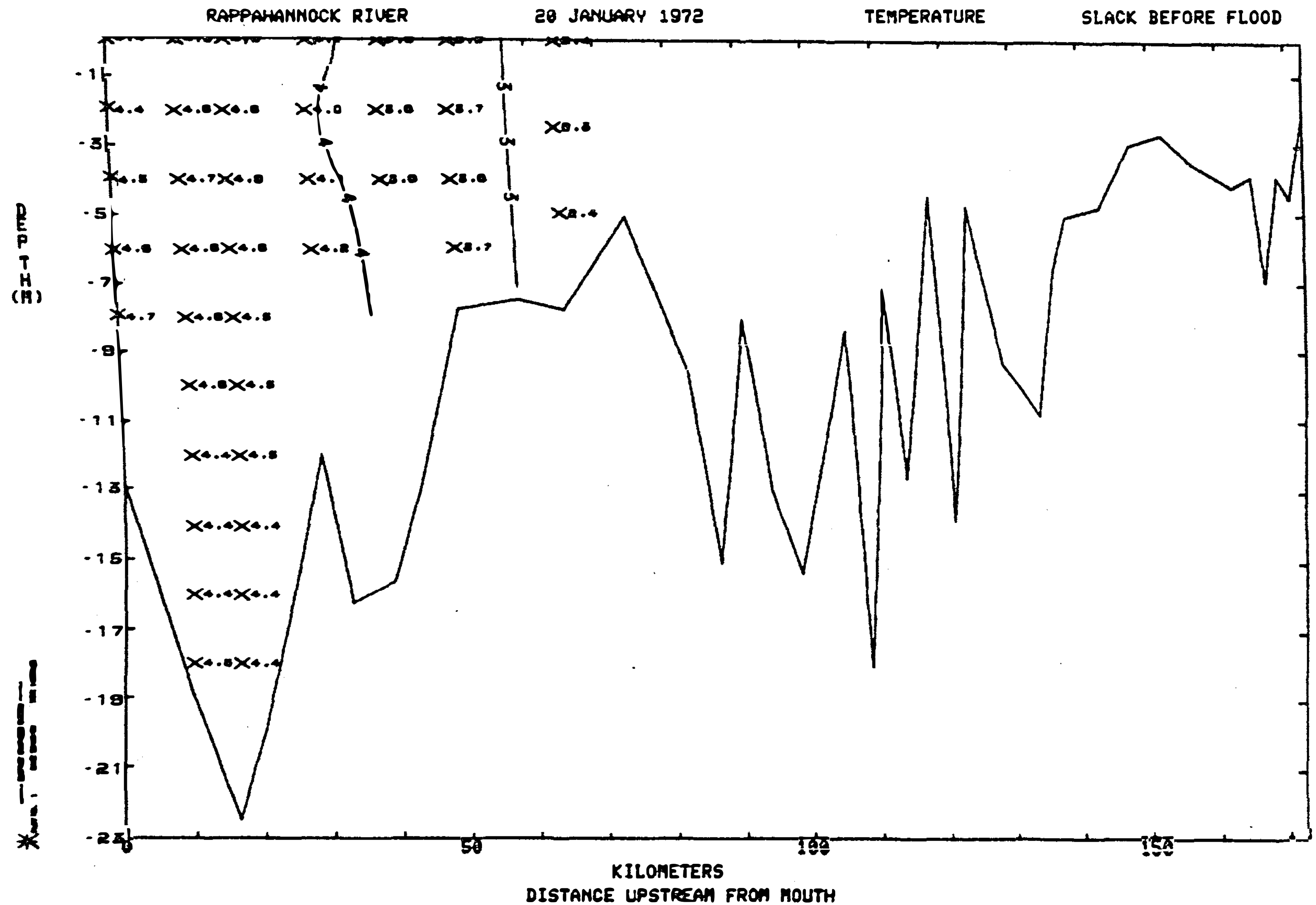
RAPPAHANNOCK RIVER
31 JULY 1971
TEMPERATURE
SLACK BEFORE EBB
DEPTH (M)
KILOMETERS
DISTANCE UPSTREAM FROM MOUTH


RAPPAHANNOCK RIVER
31 AUGUST 1971
TEMPERATURE
SLACK BEFORE EBB
DEPTH (M)
-1
-3
-5
-7
-9
-11
-13
-15
-17
-19
-21
-23
0
50
100
150
KILOMETERS
DISTANCE UPSTREAM FROM MOUTH

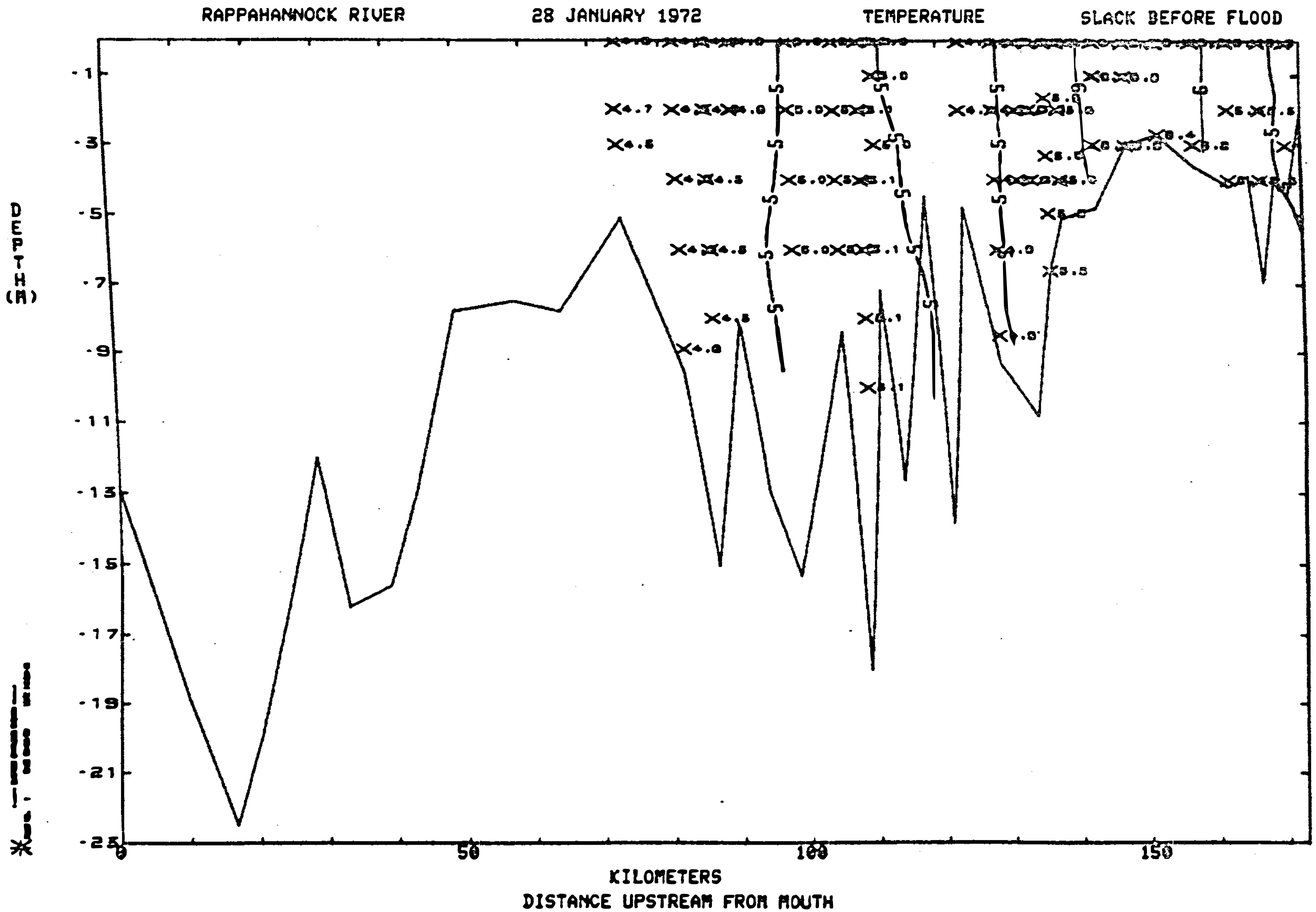

RAPPAHANNOCK RIVER
20 SEPTEMBER 1971
TEMPERATURE
SLACK BEFORE FLOOD
DEPTH (M)
-1
-3
-5
-7
-9
-11
-13
-15
-17
-19
-21
-23
0
50
100
150
KILOMETERS
DISTANCE UPSTREAM FROM MOUTH


RAPPAHANNOCK RIVER
27 OCTOBER 1971
TEMPERATURE
SLACK BEFORE FLOOD
DEPTH (M)
KILOMETERS
DISTANCE UPSTREAM FROM MOUTH

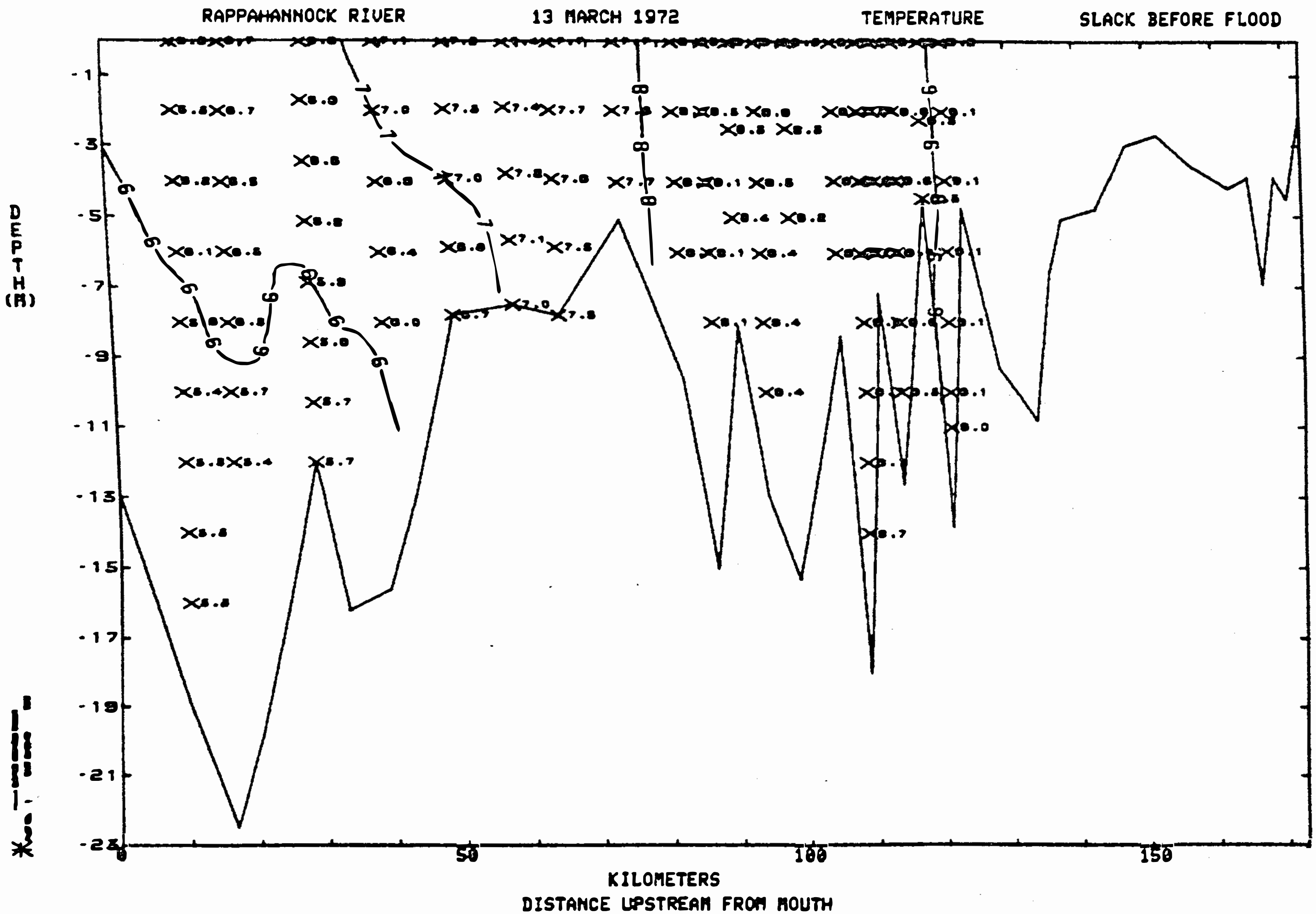

RAPPAHANNOCK RIVER
24 NOVEMBER 1971
TEMPERATURE
SLACK BEFORE EBB
DEPTH (M)
-1
-3
-5
-7
-9
-11
-13
-15
-17
-19
-21
-23
0
50
100
150
KILOMETERS
DISTANCE UPSTREAM FROM MOUTH



RAPPAHANNOCK RIVER
20 JANUARY 1972
TEMPERATURE
SLACK BEFORE FLOOD
DEPTH (M)
KILOMETERS
DISTANCE UPSTREAM FROM MOUTH



RAPPAHANNOCK RIVER
28 JANUARY 1972
TEMPERATURE
SLACK BEFORE FLOOD
DEPTH (M)
-1
-3
-5
-7
-9
-11
-13
-15
-17
-19
-21
-23
0
50
100
150
KILOMETERS
DISTANCE UPSTREAM FROM MOUTH


RAPPAHANNOCK RIVER
13 MARCH 1972
TEMPERATURE
SLACK BEFORE FLOOD
DEPTH (M)
KILOMETERS
DISTANCE UPSTREAM FROM MOUTH