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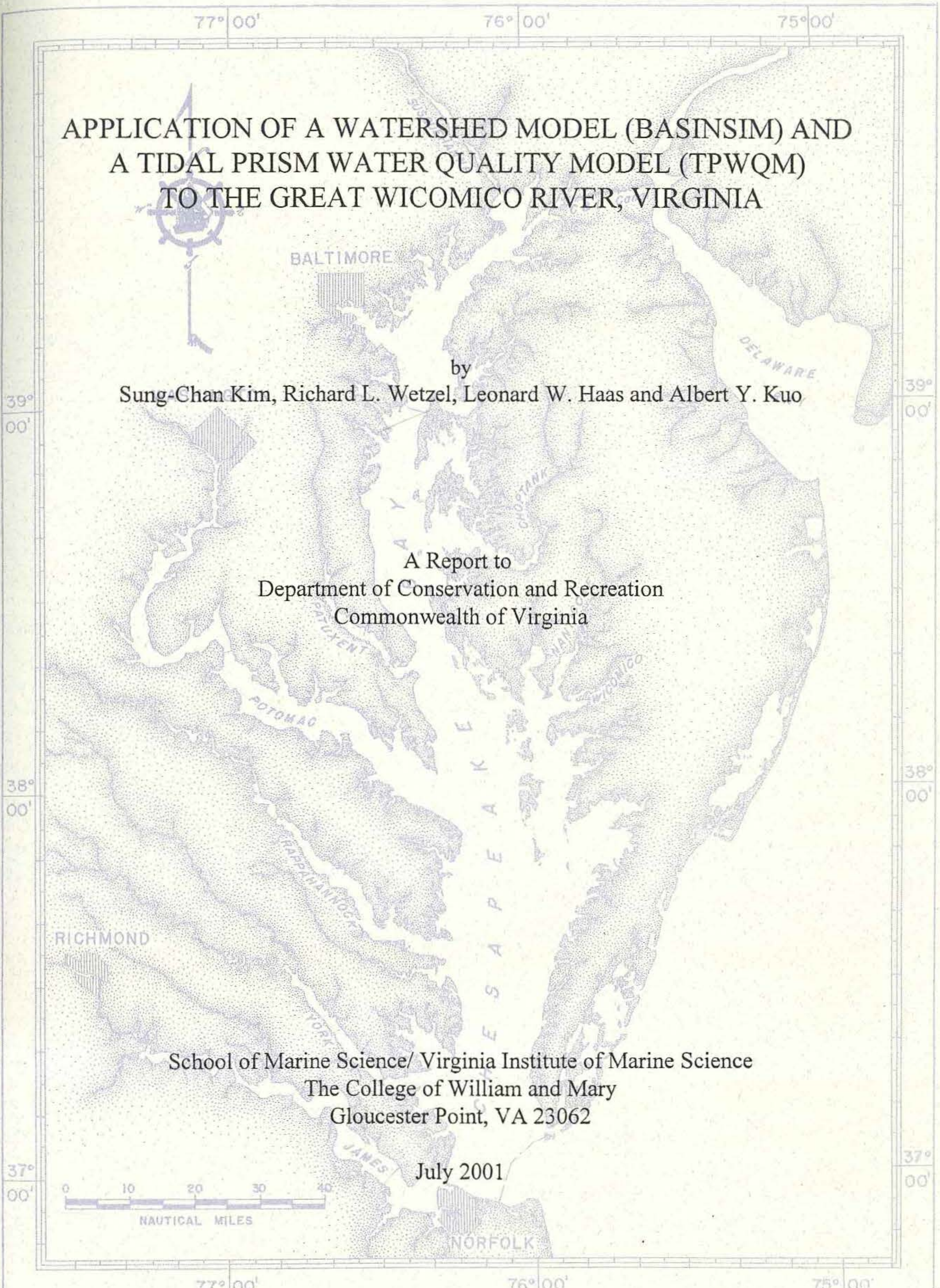

APPLICATION OF A WATERSHED MODEL (BASINSIM) AND A TIDAL PRISM WATER QUALITY MODEL (TPWQM) TO THE GREAT WICOMICO RIVER, VIRGINIA

by

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A Report to
Department of Conservation and Recreation
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Table of Contents

Page

II. Watershed Model -BasinSim

III. Tidal Prism Water Quality Model

List of Tables

List of Figures

Acknowledgements

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I. Introduction

The objective of this project is to develop a modeling package to assist in water quality management of small coastal basins (SCBs) of the Chesapeake Bay system. Efforts by the Commonwealth to address water quality and its effect on living resources in tidal, estuarine systems has focused primarily on the Chesapeake Bay and the major tributaries of the lower bay (James, York and Rappahannock Rivers), as evidenced by the extensive monitoring and modeling efforts directed to them. This has been at the expense of smaller coastal basins such as the Great Wicomico River and the numerous tidal creek systems of the Eastern Shore. In many instances there is insufficient information about water quality and living resources in SCBs to even identify system problems, much less to determine what, if any, management action to take. Despite the lack of directed efforts in the small coastal basins, these areas represent significant habitat for living resources that warrant protection from impaired water quality conditions.

Small coastal basins present their own set of characteristics that may either justify greater attention or shape a directed study. The reduced watershed area of SCBs, compared to the major tributaries, means that watershed effects on water quality are proximate rather than separated by a greater distance. Therefore land use and water quality is more tightly coupled in space and time and can be both more directly defined and addressed in nutrient reduction strategies. The reduced freshwater input to many SCBs compared to the major tributaries results in greatly reduced flushing in these systems and thus a greater tendency for SCBs to trap or retain nutrients, sediments and organic materials, with the expected negative consequences on water quality and living resources. On the other hand, because of their generally small size and proximity to the Chesapeake Bay or other larger downstream systems, there is a potential for enhanced exchange of water and materials between SCBs and those downstream systems. Reduced freshwater input at the upstream end also favors the intrusion from the downstream end member. Since it is possible that this exchange might have greater influence on water quality in a particular SCB than either point or nonpoint sources within the SCB, it is crucial that all sources of materials to SCBs and their effect on water quality be quantified and evaluated before nutrient management strategies are defined.

Since 1998, the Virginia Institute of Marine Science (VIMS) has been studying the Great Wicomico River (GWR) system to elucidate the relationship between nutrient enrichment, the presence of *Pfiesterza piscicida* and lesion prevalence in young menhaden. A primary reason for choosing the GWR is the small size of the river and watershed, a size which is typical of many Virginia SCBs and permits observation of water quality conditions and biological processes on a scale as small as the numerous tributary creeks. This ongoing study of water quality in the GWR provides an opportunity for investigating the influence of land use in the local watershed on water quality in the receiving waters by applying simulation models of the watershed and water body. VIMS has developed a watershed simulation model, BasinSim (Dai et al., 2000), and a water quality model, TPWQM (Kuo and Park, 1994), both specifically designed for application to SCBs. BasinSim relates sediment-nutrient loads to land use/land cover in small watersheds. TPWQM calculates water quality conditions in SCBs, given the loading inputs from point and nonpoint sources. The main task of this project is, using the Great Wicomico River as a demonstration site, to apply these two models to relate land use/land cover to water quality conditions in a small coastal basin.

II. Watershed Model - BasinSim

A. Background

BasinSim is a desktop, Windows-based watershed simulation system (Dai et al., 2000). The system has user-friendly graphic interfaces that allow users to view the land use, climate, and water-quality databases at county and smaller watershed levels. It also includes a watershed model that is seamlessly linked to the land use database to derive the nonpoint source loads. The simulation system extracts information from the databases and then assembles the complete input files for running the model based on user specifications. Users can run the model to test the effects of various scenarios, including changes in land use patterns and loading parameters, on total nutrient and sediment output from the watershed.

The watershed model that is built into BasinSim is the Generalized Watershed Loading Function (GWLF) model developed by researchers at Cornell University (Haith and Shoemaker 1987, Haith et al. 1992). The GWLF model has a hydrological component (necessary for transporting nutrients and sediments), and uses loading functions to calculate nutrient output. Loading functions represent a middle ground between the empiricism of export-coefficient models and the complexity of chemical simulation models (Haith et. al. 1992). The GWLF includes dissolved and particulate nitrogen and phosphorus in stream flow, which is simulated as the sum of groundwater discharge, rural runoff, and urban runoff. The dissolved nutrients originate from point sources, groundwater and rural runoff, whereas the particulate nutrients are carried by rural runoff as well as urban runoff.

$$LD = DP + DR + DG + DS \quad (1)$$

$$LS = SP + SR + SU \quad (2)$$

Here, LD is dissolved nutrient load, LS is particulate nutrient load. DP, DR, DG, and DS represent loadings of dissolved nutrients from point sources, rural runoff, groundwater, and septic systems, respectively. SP, SR, and SU represent loadings of particulate nutrients from point sources, rural runoff, and urban runoff, respectively.

Dissolved loads, LD, is obtained by multiplying runoff by dissolved nutrient concentrations. Runoff is calculated from daily weather data by using the Soil Conservation Service Curve. SR is given by the product of monthly watershed sediment yield and average sediment nutrient concentrations. Sediment yields are produced by erosion, which is computed using the Universal Soil Loss Equation. Urban runoff, SU, comes from the washoff load. Groundwater nutrient load is the product of nutrient concentration in groundwater and groundwater discharge to the stream. Groundwater discharge is described by the lumped parameter model. Daily water balances for the unsaturated and shallow saturated zones are

$$U_{i+1} = U_i + R_i + M_i - Q_i - E_i - PC_i \qquad (3)$$

$$S_{i+1} = S_i + PC_i - G_i - D_i \qquad (4)$$

Here, U_i and S_i are the unsaturated and shallow saturated zone soil moistures at the beginning of day i. R_i, M_i, Q_i, E_i, PC_i, G_i, and D_i are rainfall, snowmelt, runoff, evapotranspiration, percolation into the shallow saturated zone, groundwater discharge to the stream, and seepage flow to the deep saturated zone on day i, respectively.

B. Model Set-Up

Topographic and land use data for the GWR watershed were downloaded from the USEPA BASIN database. The Great Wicomico River Basin was extracted from the EPA BASIN database that covers both the Piankatank and the Great Wicomico watersheds. The Great Wicomico River watershed was further divided into 15 sub-basins (Figure 2-1) for the purpose of applying BasinSim. The subdivision of the watershed is necessary because of the input requirements of the Tidal Prism Water Quality Model (TPWQM). Each sub-basin generally follows the drainage area of each individual tributary stream or creek. Table 2-1 tabulates the land use/land cover data of each of the sub-basins.

The BasinSim model simulation period was set for the 2 year period between April 1, 1998 and March 31, 2000. The BasinSim model requires land use data, weather data, transport parameters, and nutrient parameters. A total of 8 different types of land uses (6 rural and 2 urban land use types) were specified for all sub-basins (Table 2-1). Weather data containing air temperature and precipitation were provided by a private citizen (Cupp, 2000) who has made meteorological measurements near Reedville in recent years (Fig 2-2 and Fig 2-3). For the transport parameters, the following values were used:

Parameter	**Value**
Groundwater recession coefficient	0.05
Groundwater seepage coefficient	0
Unsaturated zone soil moisture initial condition	10
Shallow saturated zone soil moisture initial condition	0
Snow cover initial condition	0
Sediment delivery ratio	0.107
5 day antecedent rain fall plus snowmelt initial condition	0,0,0,0,0

Monthly parameters were set as:

Month	**Evapotranspiration cover factor**	**Average daylight hour**	**Growing season indicator**	**Rainfall erosivity coefficient**
April	98	13.1	1	3
May	98	14.1	1	3
June	98	14.6	1	3
July	98	14.4	1	3
August	98	13.5	1	3
September	98	12.2	1	3
October	98	10.9	1	12
November	98	9.9	0	12
December	98	9.4	0	12
January	98	9.6	0	12
February	98	10.5	0	12
March	98	11.8	0	12

For each land use, transport parameters were set as:

Type	**Runoff curve number for moisture condition**	**Erosion product**
Crops	9.81	0.01570
Hay/pasture	63.50	0.00033
Forest	60.00	0.00011
Barren	86.00	0.08460
Wetland	95.00	0
Water	100.00	0
Urban-HDD	84.00	0
Urban-LDD	96.00	0

For each land use/land cover, nutrient parameters were set as

Type	**Dissolved nitrogen in runoff** (mg/l)	**Dissolved phosphorus in runoff** (mg/l)
Crops	2.9	0.26
Hay/pasture	2.9	0.20
Forest	0.19	0.006
Barren	2.6	0.1
Wetland	0	0
Water	1	0
Urban-HDD	0.0186	0.0022
Urban-LDD	0.0832	0.0093

No point source and septic system inputs were assumed.

C. Field Monitoring

To collect data for calibration/verification of BasinSim, three stations in feeder streams were selected for monitoring the quantity and quality of freshwater flows during the period from August 1999 to March 2000. They are the abandoned USGS gauging stations in Bush Mill Stream and Crabbe Mill Stream, and one location upstream of the tidal limit in Tippers Creek. It was observed that all stations had no flow during the dry period. Therefore all measurements except the first one were made shortly after precipitation. Table 2-2 lists all measured data. The data are also presented in graphical form in Figures 2-4 to 2-8.The data measured at station M6 of the mainstem Great Wicomico River are also presented in the figures for comparison. The figures show that the nutrient, carbon and suspended sediment concentrations in the mainstem Great Wicomico River are of the same order of magnitude or higher than those in the feeder streams.

The mainstem water quality station M6 is located below the junction of the Bush Mill Stream and Crabbe Stream. The average salinity there ranges from 55 to 75% of that at the river mouth during the period of feeder stream monitoring. Therefore the freshwater from the watershed contributes no more than 45% of the water volume at this location. The fact that the nutrient concentrations in the feeder streams are of the same order of magnitude or less suggests that the watershed runoff is not a major contributor of nutrients to the mainstem of the river. The dominant source may be bay water and/or groundwater.

D. Model Application

The only continuous discharge record in the watershed is at the USGS gauging station in the Bush Mill Stream which operated from April 1971 to March 1985. Therefore the model for the Bush Mill Stream sub-basin was run to simulate this period to examine the model prediction of freshwater discharge. Unfortunately there is no precipitation data measured during the same period within the watershed. The precipitation data at a nearby station, Warsaw, were obtained from the Virginia Climatologist Office and used as model input. The model output of average monthly discharges are compared with USGS gauging record in Figures 2-9 and 2-10. Figure 2-9 is the scatter plot of simulated versus observed flows. It indicates that the model under predicts the discharge during extreme low flows, and over predicts the higher flows. This may be attributed to the under estimation of the detention parameter in the model. However the time series comparison in Figure 2-10 indicates that these same discrepancies do not exist for the period after 1982. Therefore no attempt was made to adjust the detention parameter used in the model.

The model was then run to simulate the conditions from April 1998 to March 2000, encompassing the period when feeder stream monitoring was conducted. Samples of the model calculated stream flows, total nitrogen, total phosphorus and sediment loads are presented in Figures 2-11 to 2-14. The calculated flows are monthly averages. The nutrient and sediment loads are the total monthly loads. Both the flows and loads are composed of two components: the surface runoff and groundwater discharge. Since the feeder stream measurements were taken following rainfall events at one instant each time, it is not appropriate to compare the measured flows with model results. To compare the nutrient and sediment loads with feeder stream measurements, the monthly weighted-average concentrations were computed as the total monthly loads divided by the total volume of flow in the month. Figures 2-15 and 2-16 present the results for the Bush Mill Stream sub-basin. They indicate that the calculated total phosphorus concentrations remain relatively constant throughout the year, while the calculated total nitrogen and sediment concentrations are more variable. The total nitrogen concentrations are very high in the summer when the flows are very low. The sediment concentrations vary widely responding to the magnitude of stream flows, with high concentration during high flow. The average calculated concentrations over the period from August 1999 to March 2000 are compared with those of feeder stream measurements in Table 2-3. This shows that the calculated and measured average nutrient concentrations agree within 10 to 20 %. A large discrepancy exists for sediment concentrations. Figure 2-16 shows that very high sediment concentrations, 100 to 200 mg/l, occur during high runoff months. This is contrary to the instream measurements, which have most sediment concentrations ranging between 10 to 20 mg/l (Table 2-2).

The comparison of the model results with the field data demonstrates that the watershed model BasinSim is accurate in terms of overall average total nitrogen and total phosphorus concentrations. It may over estimate the sediment yield in the watershed.

Table 2-1. Landuse/cover areas (in ha) for the model sub-basins.

Sub-basin	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	sum
Crops	546	263	100	72	87	71	46	83	41	34	60	85	37	26	125	1677
Hay /pasture	534	345	63	131	111	117	55	63	104	46	101	165	93	31	96	2056
Forest	3870	1504	1077	781	950	498	604	338	323	152	229	263	139	177	524	11430
Barren	287	0	0	0	43	2	2	4	0	0	0	0	0	0	0	339
Wetland	164	54	35	18	33	10	18	6	5	9	9	9	3	13	43	429
Water	32	17	129	222	95	132	89	117	108	282	296	114	116	197	564	2510
Urban-LDD	5	20	2	0	1	38	0	12	22	4	2	0	6	23	223	359
Urban-HDD	4	4	3	4	3	12	2	8	5	5	6	2	3	5	49	113
total	5441	2207	1409	1228	1324	881	817	631	608	532	703	637	398	472	1625	18913

Table 2-2. Measured flows and concentrations in feeder streams

Crabbe Mill Stream

	Q cfs	PC/POC mg/l	PN mg/l	TDN mg/l	DON* mg/l	NH4 mg/l	NO3 mg/l	PP mg/l	POP* mg/l	PIP mg/l	TDP mg/l	DOP* mg/l	PO4f mg/l	TSS mg/l	TFS mg/l	DOC mg/l
8/4/99	0	1.37	0.143	0.516	0.31	0.072	0.134	0.087	0.026	0.061	0.012	0.003	0.009	11	5	
8/26	11.5	1.37	0.116	0.484	0.355	0.034	0.095	0.052		no dat	0.024	0.019	0.005	18	13	
9/17	72.1	1.3	0.103	0.591	0.474	0.04	0.077	0.035	0.015	0.02	0.02	0.01	0.01	17	9	10.8
9/22	26.1	1.13	0.094	0.547	0.395	0.036	0.116	0.031	0.014	0.017	0.024	0.012	0.012	9	1	
10/19	0															
11/23		no data														
1/5/00	24.1	1.44	0.116	0.6	0.305	0.056	0.239	0.04	0.011	0.029	0.048	0.025	0.023	14	7	7.4
3/22/00	29.5	1.25	0.099	0.518	0.232	0.047	0.239	0.04	0.016	0.024	0.03	0.021	0.009	13	7	
3/28/00	22.3			0.495	0.278	0.034	0.183	0.045	0.018	0.027	0.03	0.021	0.009	13	6	
Average*			0.1342	0.539				0.041			0.029			14	7.17	

Bush Mill Stream

	Q cfs	PC/POC mg/l	PN mg/l	TDN mg/l	DON* mg/l	NH4 mg/l	NO3 mg/l	PP mg/l	POP* mg/l	PIP mg/l	TDP mg/l	DOP* mg/l	PO4f mg/l	TSS mg/l	TFS mg/l	DOC mg/l
8/4/99	0	1.96	0.209	0.693	0.504	0.131	0.058	0.117	0.042	0.075	0.032	0.01	0.022	24	15	
8/26	5.6	1.38	0.142	0.503	0.45	0.033	0.02	0.104	0.025	0.079	0.035	0.029	0.006	15	8	
9/17	57	1.51	0.132	0.611	0.529	0.032	0.05	0.049	0.017	0.032	0.037	0.017	0.02	16	9	14.5
9/22		1.33	0.116	0.55	0.477	0.032	0.041	0.061	0.019	0.042	0.037	0.018	0.019	10	4	
10/19	7.7	0.92	0.076	0.479	0.438	0.026	0.015	0.061	0.012	0.049	0.038	0.006	0.032	8	4	
11/23		no data														
1/5/00	16.2	1.35	0.126	0.463	0.341	0.035	0.087	0.08	0.047	0.033	0.065	0.041	0.024	14	6	7.86
3/22/00	33.5	1.19	0.105	0.515	0.289	0.044	0.182	0.059	0.02	0.039	0.048	0.035	0.013	18	9	
3/28/00	27.8			0.486	0.343	0.023	0.12	0.061	0.018	0.043	0.04	0.026	0.014	17	8	
Average*			0.1162	0.515				0.068			0.043			14	6.86	

* exclude 8/4/99 data when there is no flow.

Table 2- 2. Continued

Tipper Creek

	Q cfs	PC/POC mg/l	PN mg/l	TDN mg/l	DON* mg/l	NH4 mg/l	NO3 mg/l	PP mg/l	POP* mg/l	PIP mg/l	TDP mg/l	DOP* mg/l	PO4f mg/l	TSS mg/l	TFS mg/l	DOC mg/l
8/4/99	0.44	0.63	0.047	0.512	0.197	0.053	0.262	0.047	0.017	0.03	0.025		0.012	18	12	
8/26	1.06	0.64	0.047	0.391	0.273	0.05	0.068	0.029	0.012	0.017	0.028		0.005	6	3	
9/17		0.96	0.074	0.473	0.42	0.019	0.034	0.025	0.01	0.015	0.02		0.011	10	5	10.9
9/22	11.9	0.88	0.059	0.407	0.351	0.022	0.034	0.026	0.011	0.015	0.027		0.016	5	1	
10/19	1.62	0.61	0.038	0.356	0.281	0.031	0.044	0.037	0.011	0.026	0.024		0.016	6	2	
11/23	1.87	1.23	0.077	0.222	0.222			0.084	0.03	0.054	0.02			14	7	4.24
1/5/00	2.73	1.14	0.078	0.302	0.198	0.037	0.067	0.05	0.012	0.038	0.031		0.014	10	5	7.65
3/22/00	4.53	1.14	0.08	0.341	0.209	0.041	0.091	0.037	0.017	0.02	0.032		0.009	11	4	
3/28/00	2.74			0.375	0.254	0.033	0.088	0.032	0.005	0.027	0.033		0.009	9	2	
Average			0.0625	0.375				0.041			0.027			9.89	4.56	

Note: Q, flow rate; PC/POC, Particulate Carbon or Particulate Organic Carbon; PN, Particulate Nitrogen; TDN, Total Dissolved Nitrogen; DON, Dissolved Organic Nitrogen; NH4, Ammonium Nitrogen; NO3, Nitrate Nitogen; PP, Particulate Phosphorus; POP, Particulate Phosphorus; PIP, Particulate Inorganic Phosphorus; TDP, Total Dissolved Phosphorus; DOP, Dissolved Organic Phosphorus; PO4f, Dissolved Phosphate; TSS, Total Suspended Solid; TFS, Total Fixed Solid; DOC, Dissolved Organic Caubon.

Table 2-3. Comparison of model predicted and measured nutrient and sediment concentrations

Sub-basin	Q(cfs)	TSS (mg/l)	TSS (mg/l) measured	TN (mg/l)	TN (mg/l) measured	TP (mg/l)	TP (mg/l) measured
0 Bush Mill St.	57.9	90	14	0.708	0.631	0.101	0.111
1 Crabbe Mill St.	25.1	27	14	0.602	0.673	0.078	0.070
2	15.3	17	-	0.514	-	0.059	-
3	13.7	15	-	0.653	-	0.053	-
4	14.3	56	-	0.633	-	0.077	-
5	9.7	22	-	0.704	-	0.064	-
6 Tipper Cr.	8.9	18	10	0.539	0.438	0.057	0.068
7	7.1	38	-	0.823	-	0.071	-
8	6.8	17	-	0.734	-	0.060	-
9	6.6	13	-	0.992	-	0.026	-
10	8.4	18	-	0.982	-	0.042	-
11	7.1	31	-	0.937	-	0.079	-
12	4.6	21	-	0.954	-	0.060	-
13	5.6	12	-	0.852	-	0.031	-
14 Cockrell Cr.	19.2	17	-	0.835	-	0.041	-

Great Wicomico River Basin Segmentations for BasinSim and TPWQM

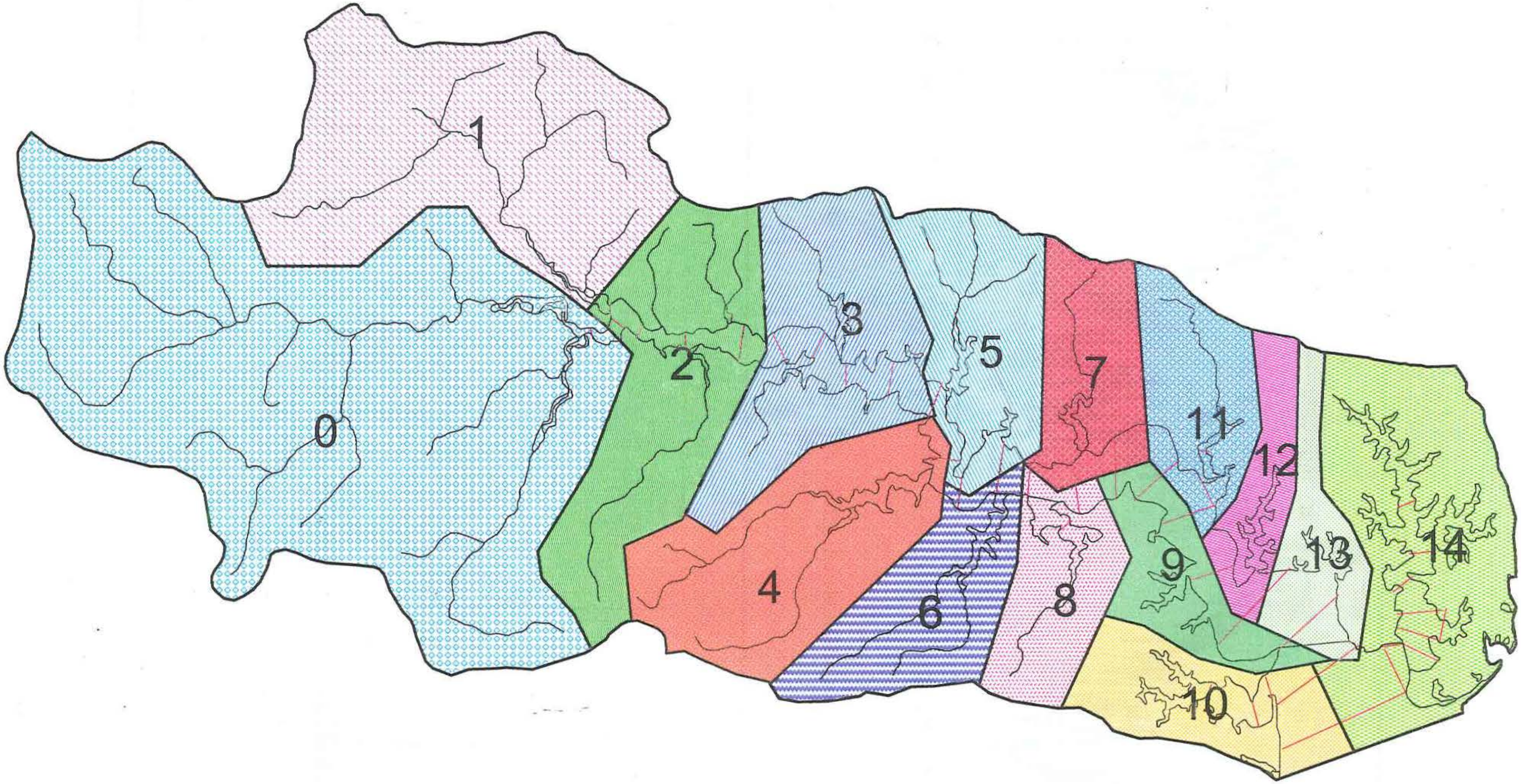


Fig. 2-1. Division of watershed into 15 sub-basins for BasinSim model application.

2 0 2 4 Kilometers

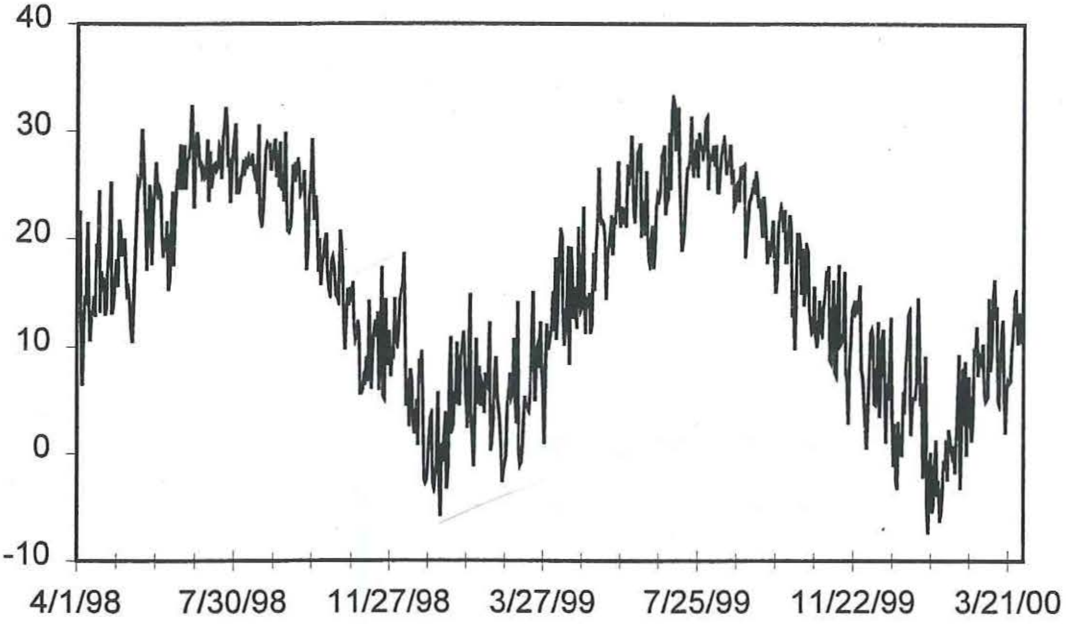


Fig 2-2. Air temperature (^{o}C) at Reedville, VA during the simulation period.

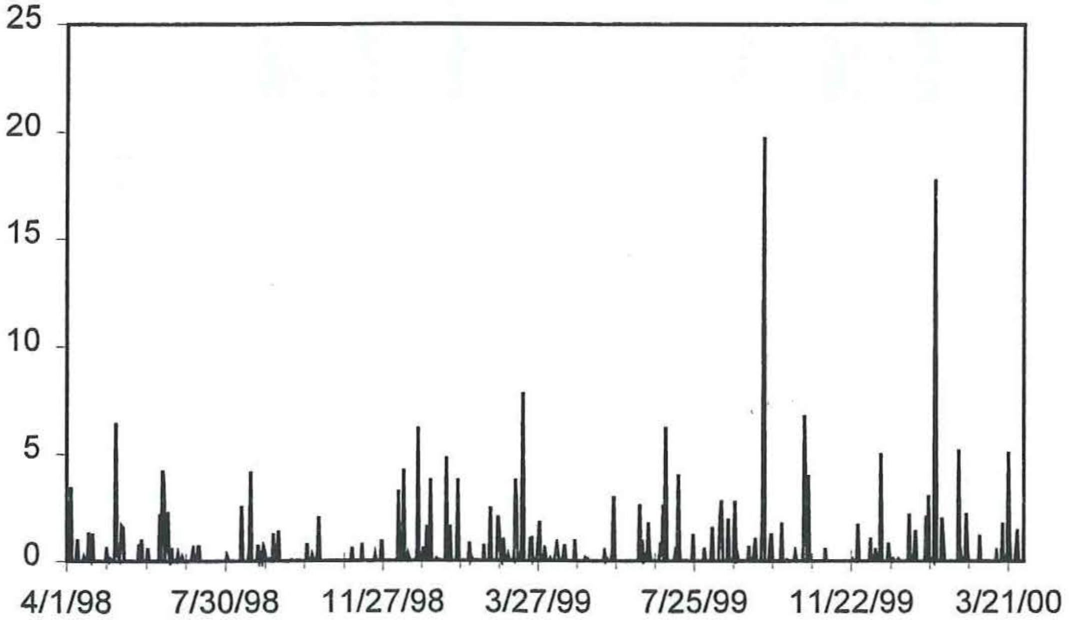
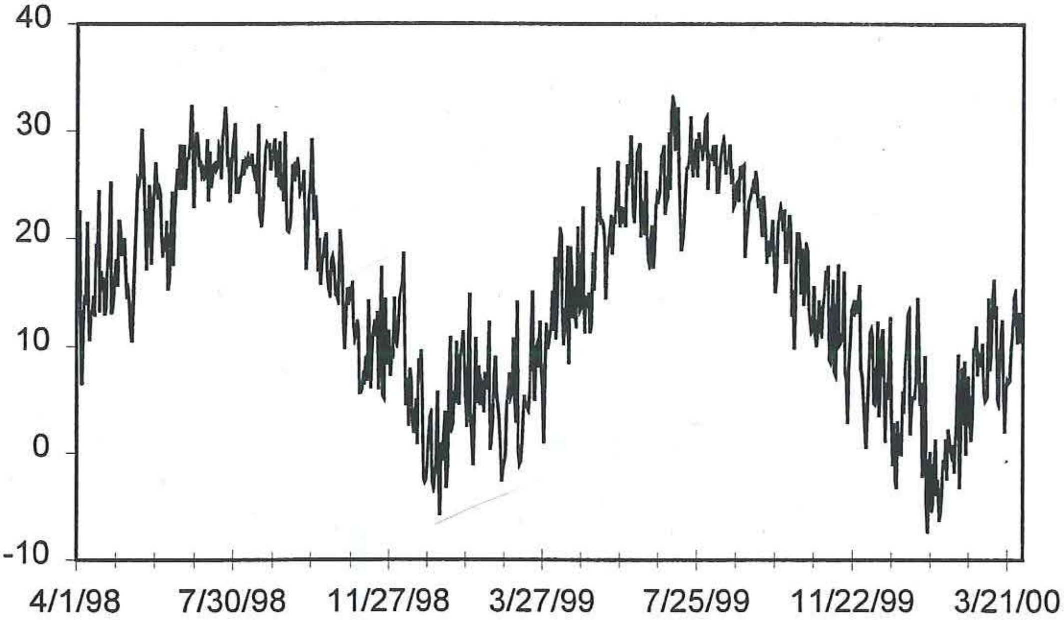


Fig 2-3. Precipitation (cm) at Reedville, VA during the simulation period.



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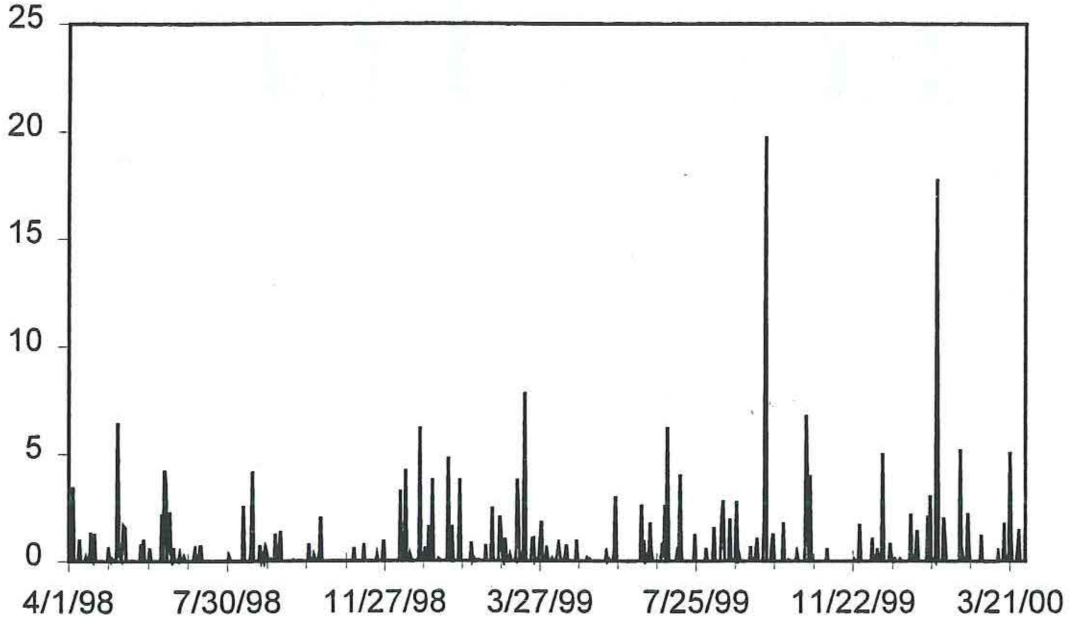

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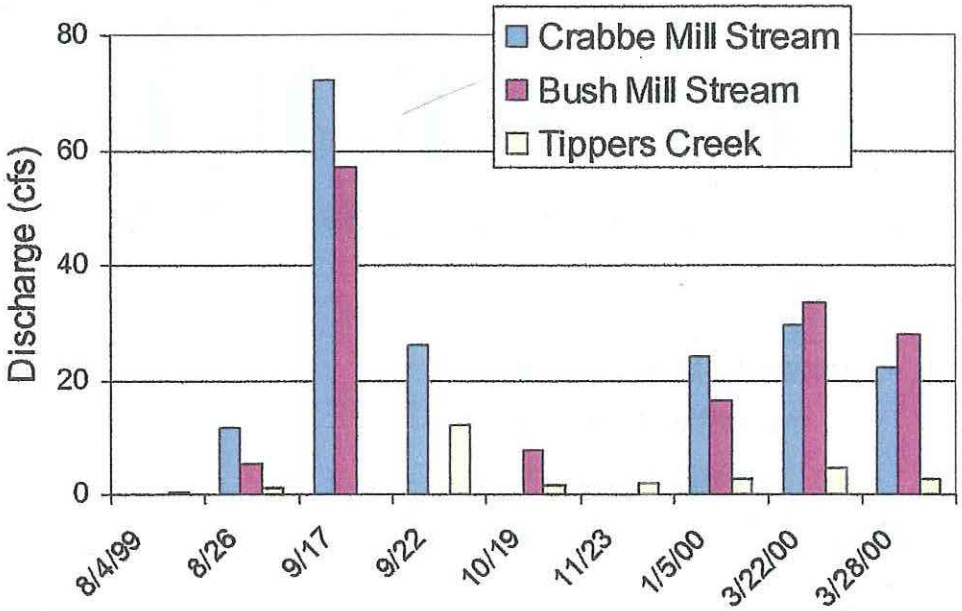
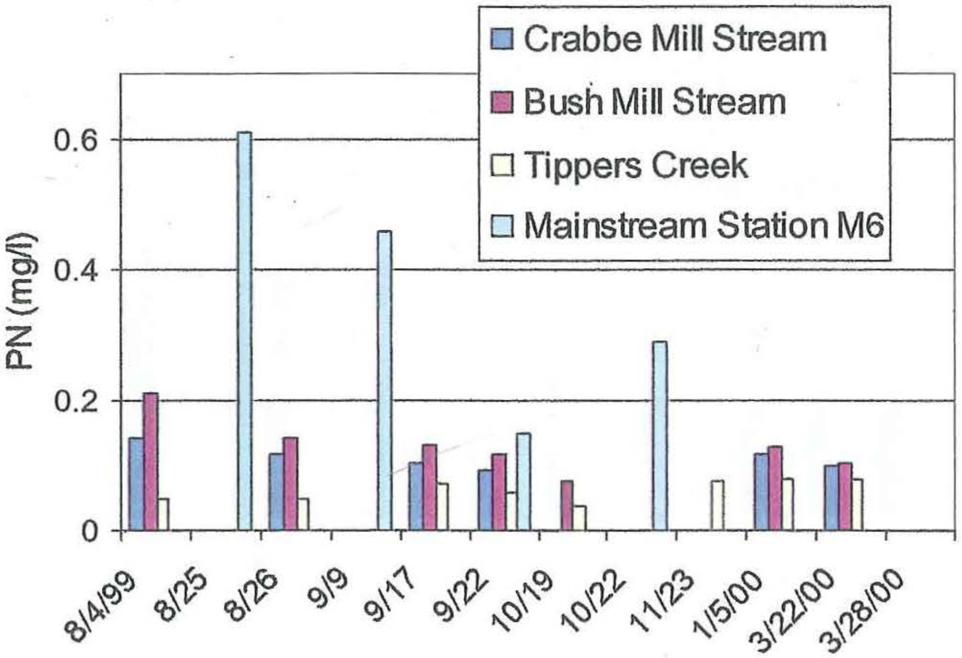


Fig. 2-4. Measured stream flows in feeder streams.



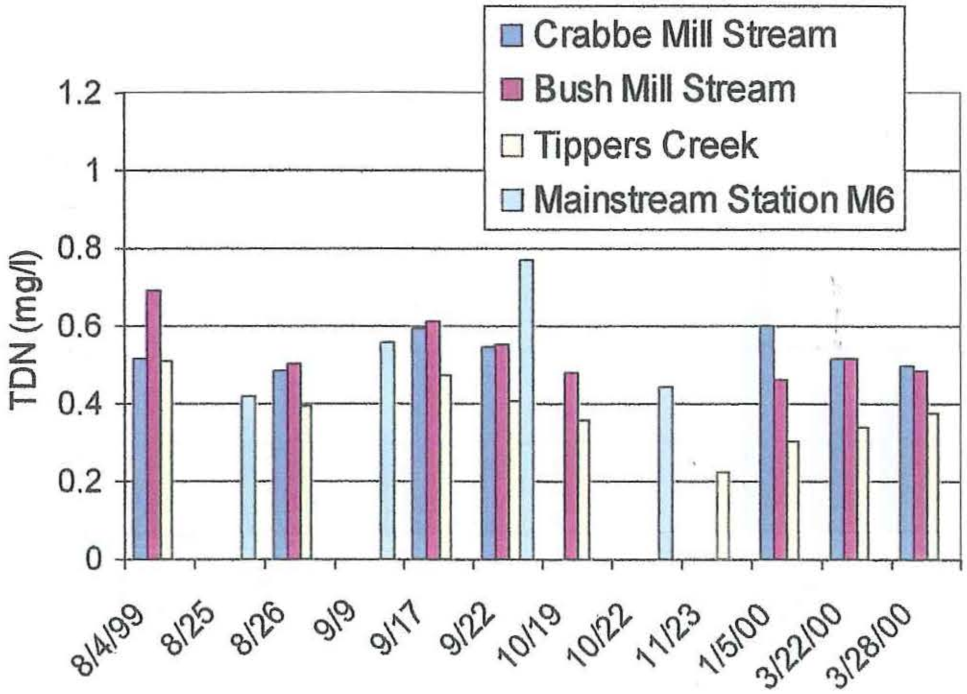


Fig. 2-5. Measured particulate and total dissolved nitrogen concentrations.

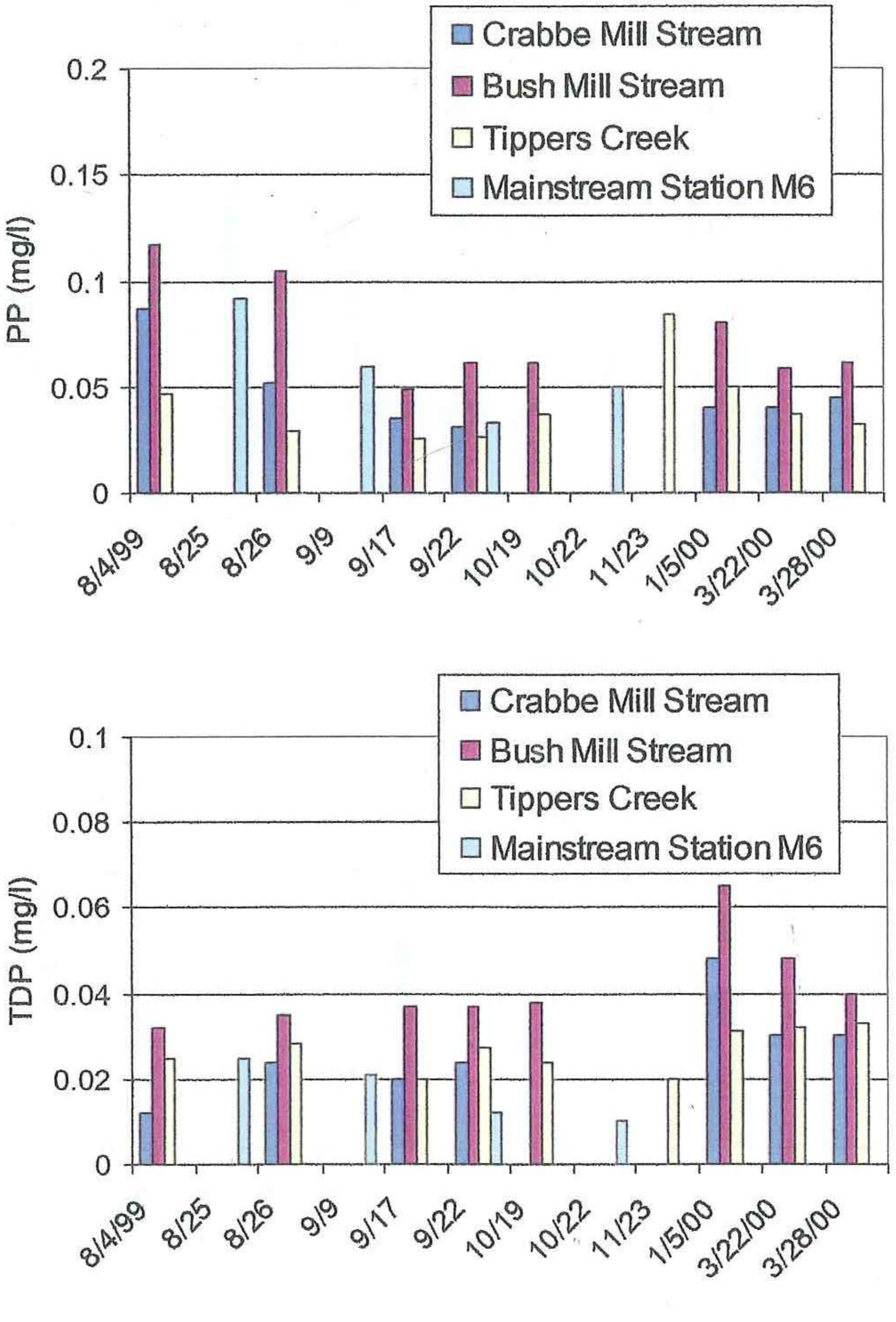
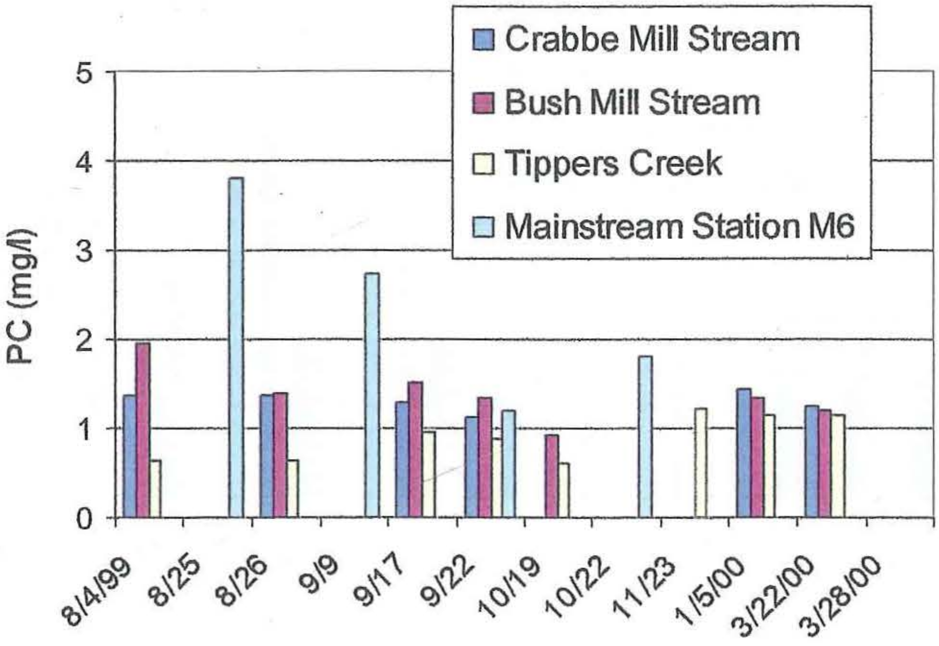


Fig. 2-6. Measured particulate and total dissolved phosphorus concentrations.



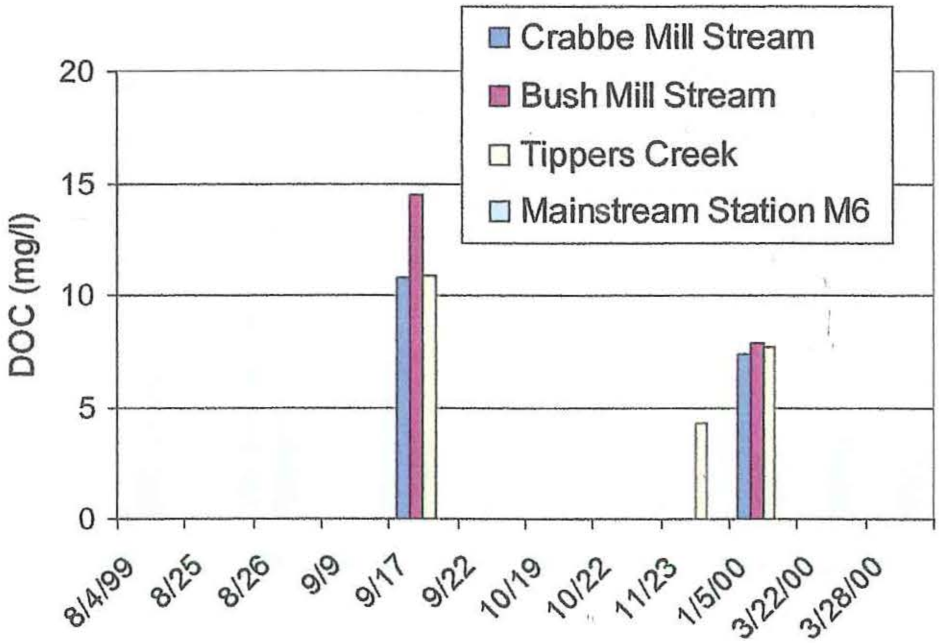
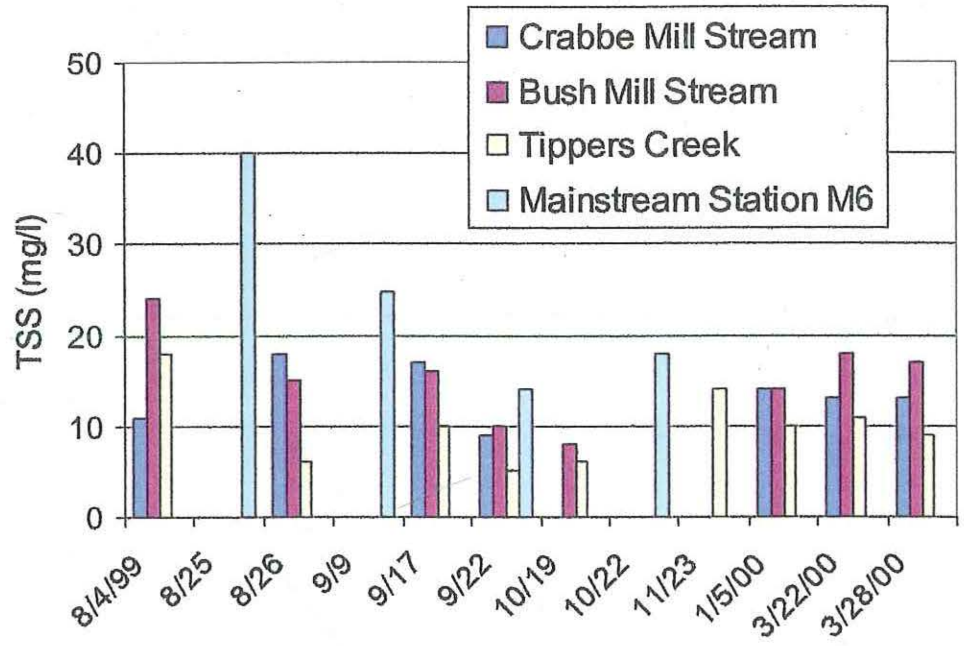


Fig. 2-7. Measured particulate and dissolved organic carbon concentrations.



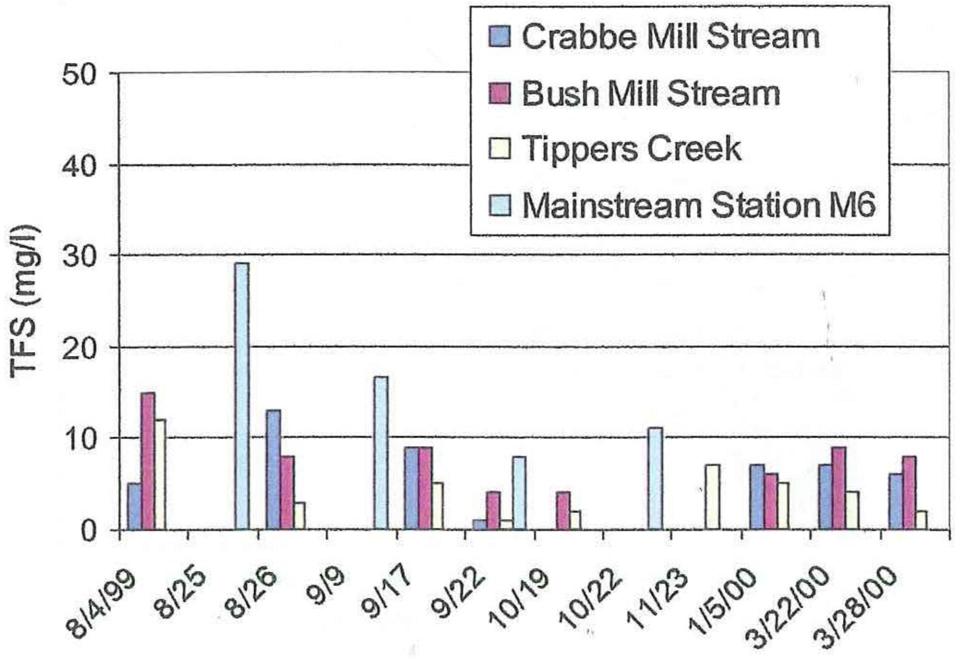


Fig. 2-8. Measured total suspended and total fixed solid concentrations.

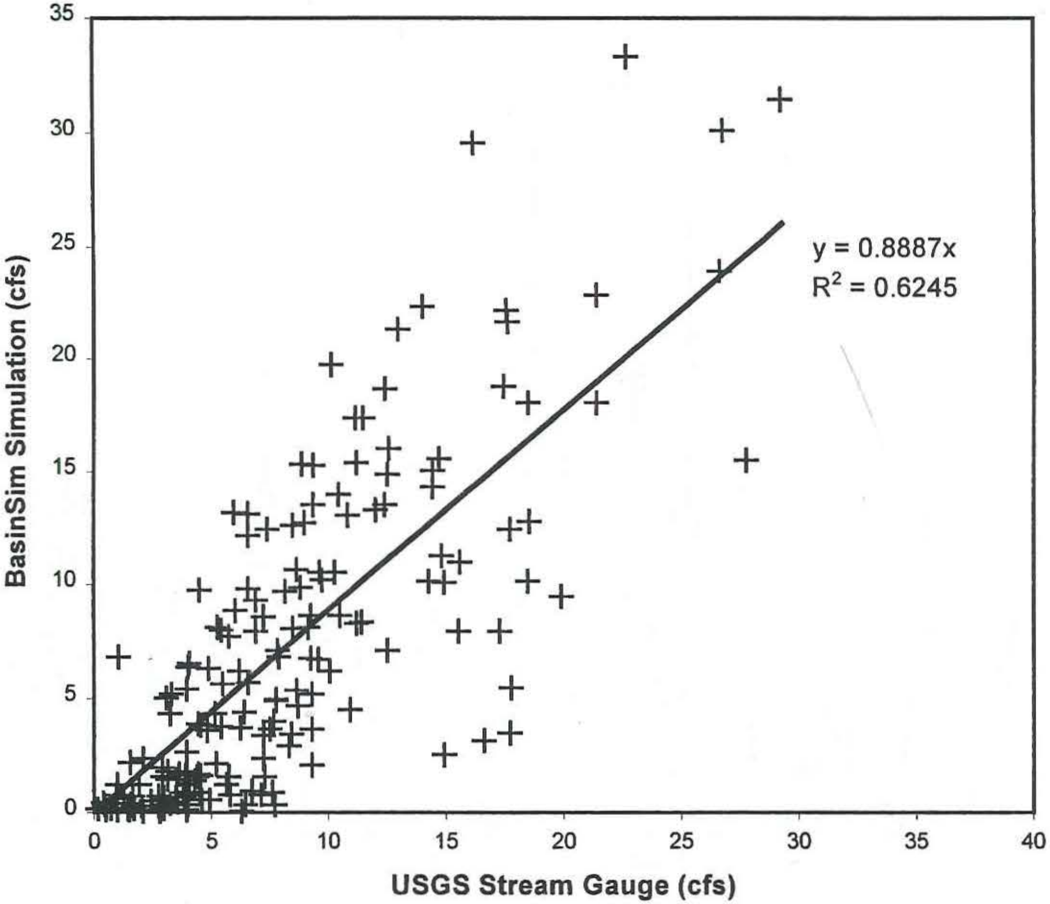


Fig 2-9. Scatter plot comparison of simulated flows (solid line) with stream gauge data (+ symbol) in Bush Mill Stream, 4/1971 – 3/1986

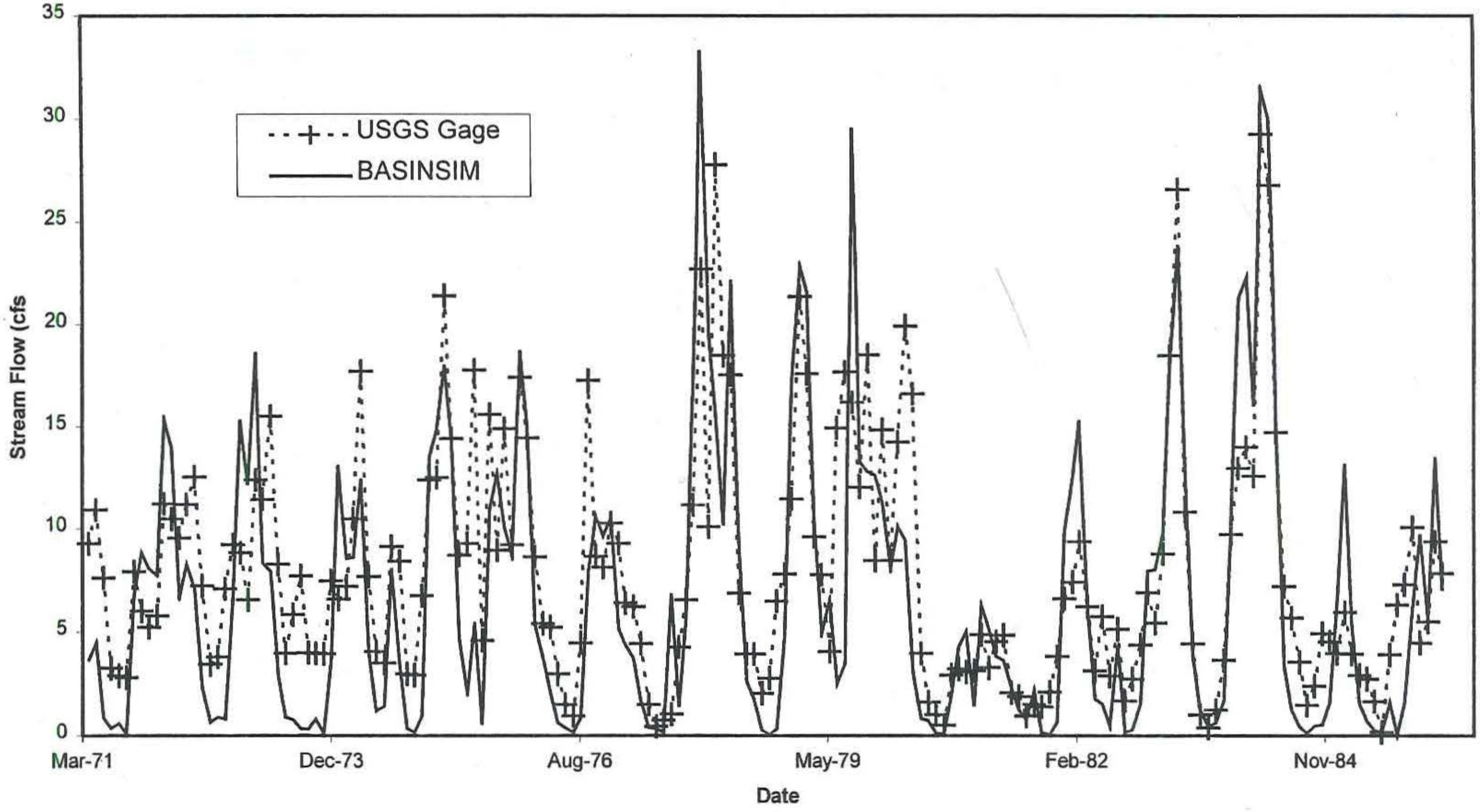


Fig 2-10. Time series comparison of simulated flows with stream gauge data in Bush Mill Stream.

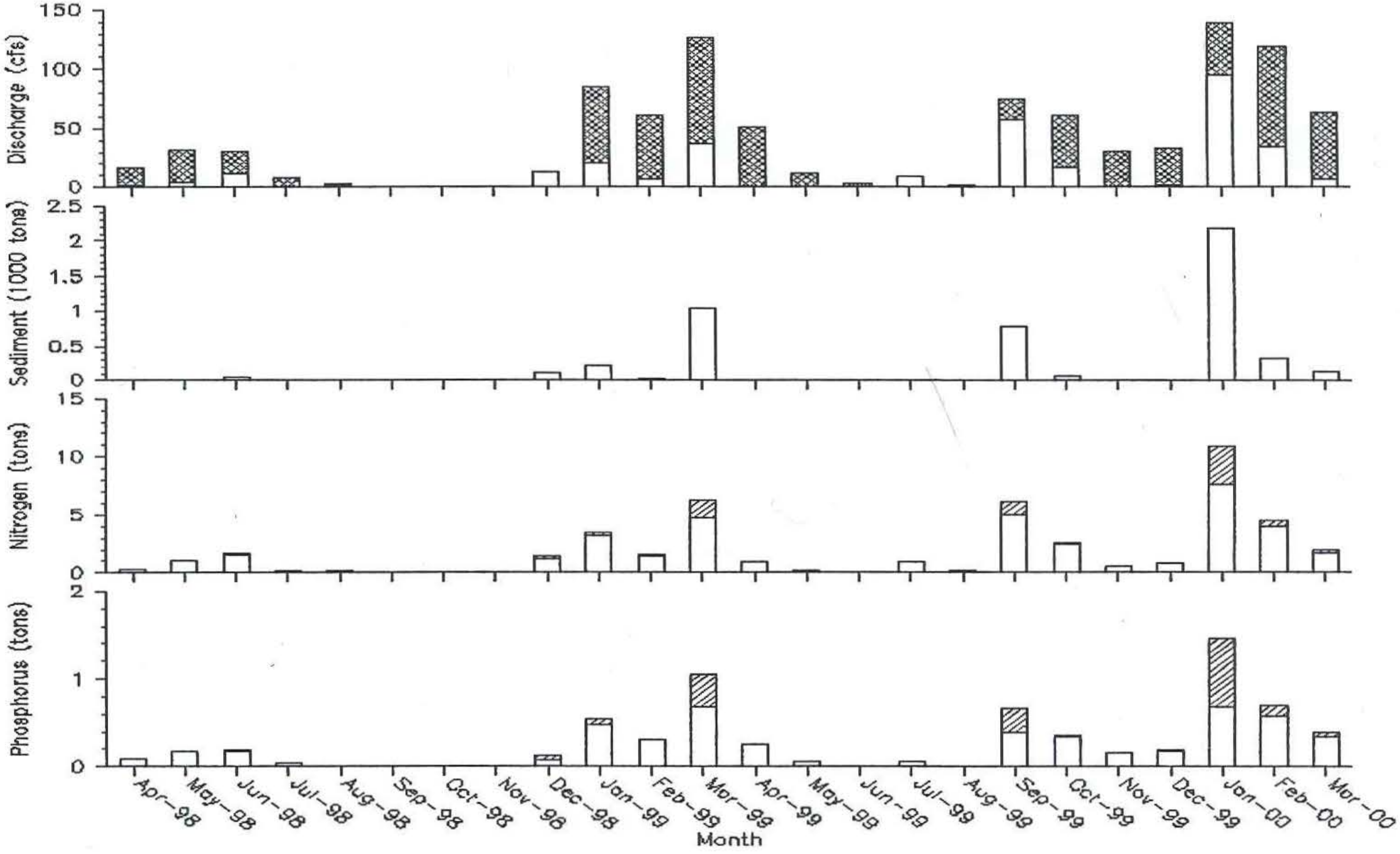


Fig 2-11. BasinSim output of stream flows and loads in Bush Mill Stream (hatched portion is groundwater discharge, blank portion is surface runoff).

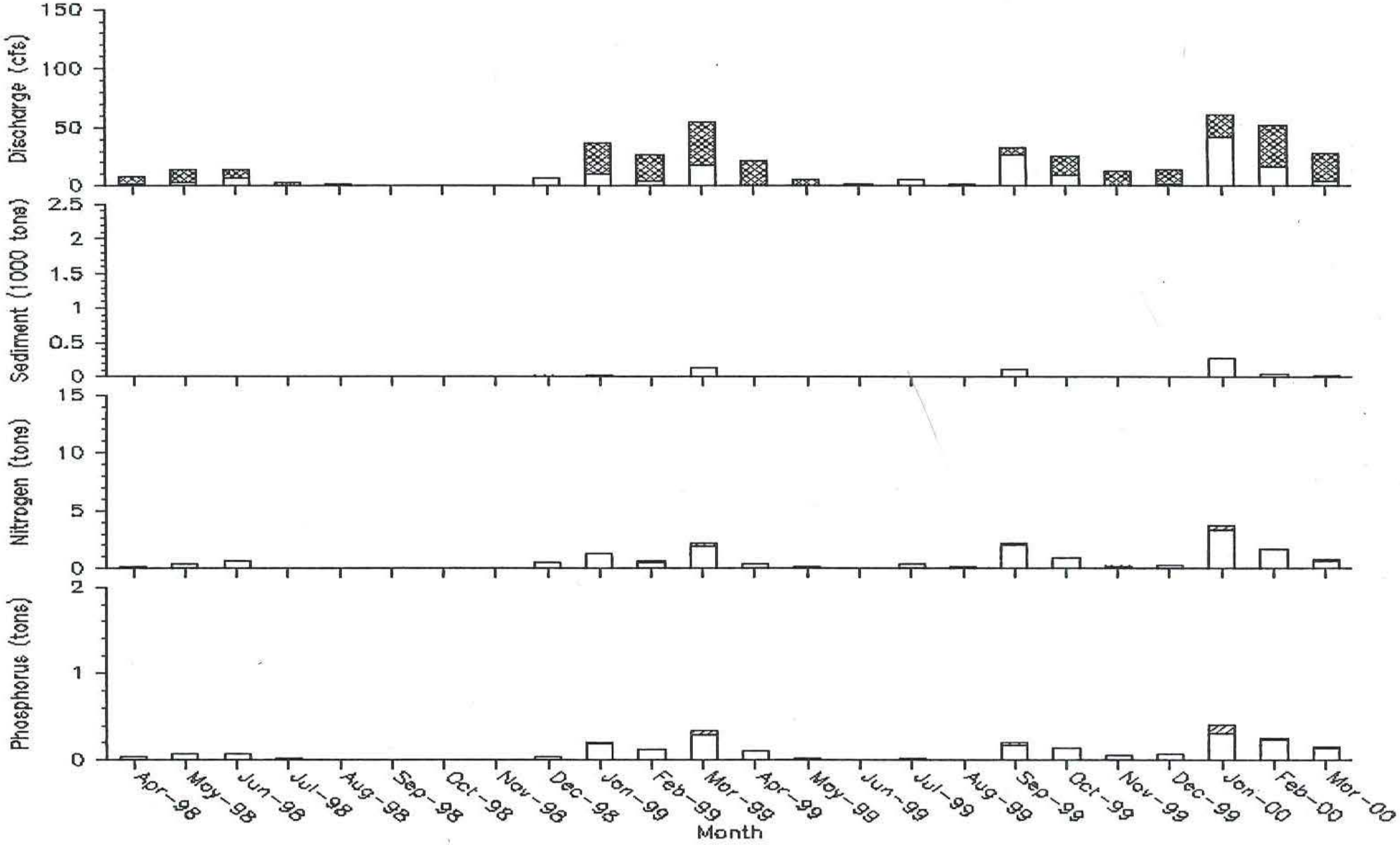


Fig 2-12. BasinSim output of stream flows and loads in Crabbe Mill Stream (hatched portion is groundwater discharge, blank portion is surface runoff).

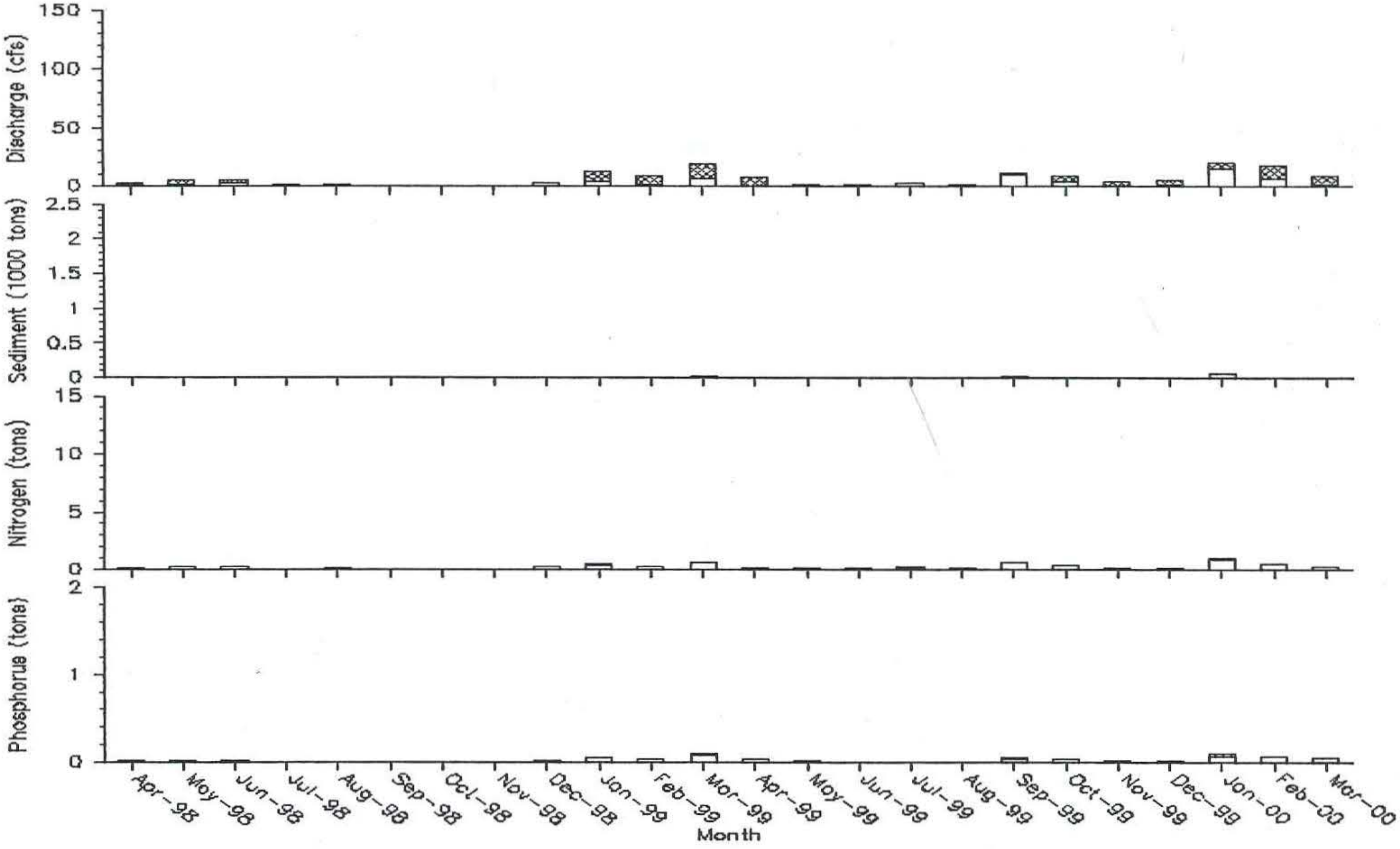


Fig 2-13. BasinSim output of stream flows and loads in Tipper Creek (hatched portion is groundwater discharge, blank portion is surface runoff).

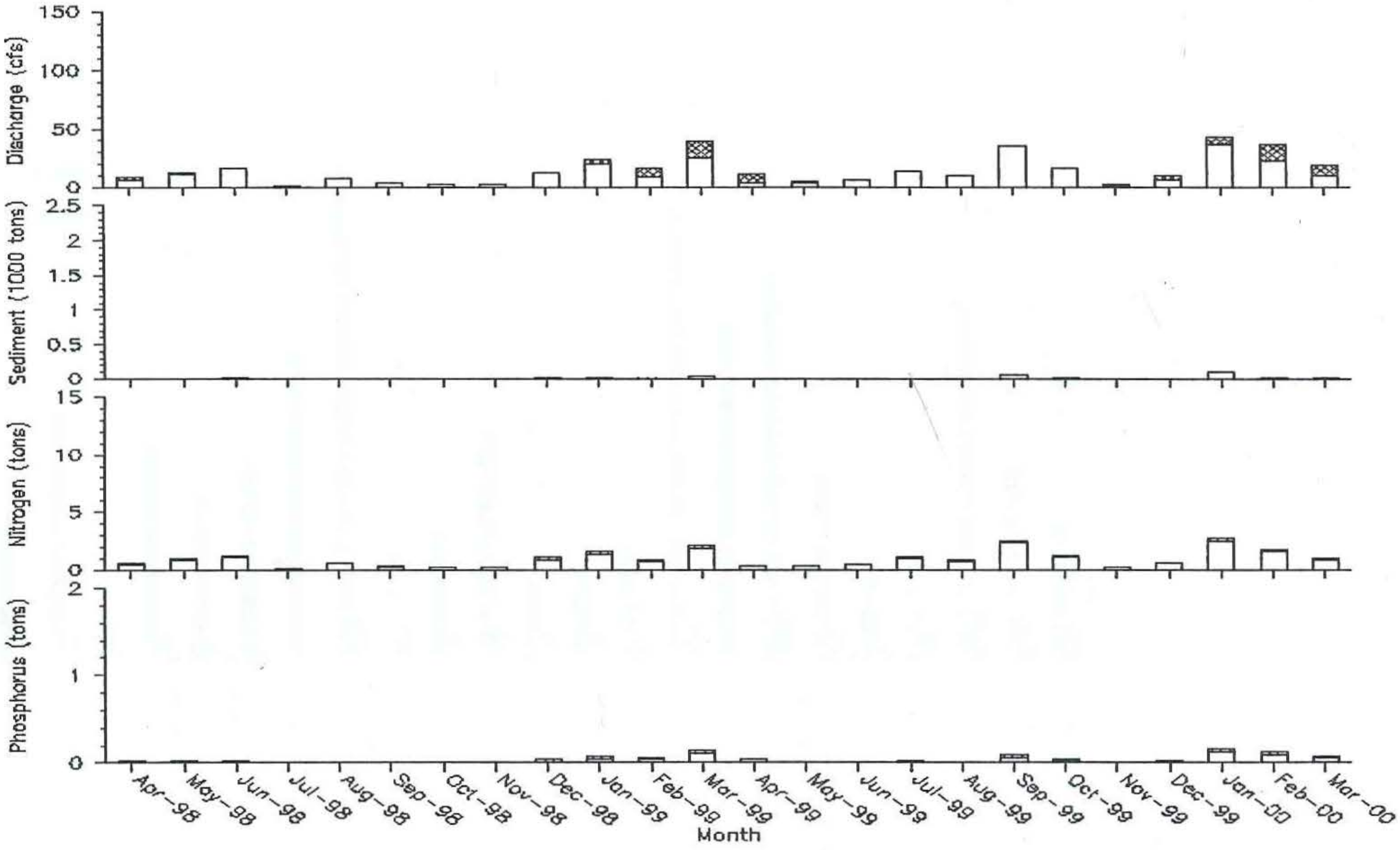


Fig 2-14. BasinSim output of stream flows and loads in Cockrell Creek (hatched portion is groundwater discharge, blank portion is surface runoff).

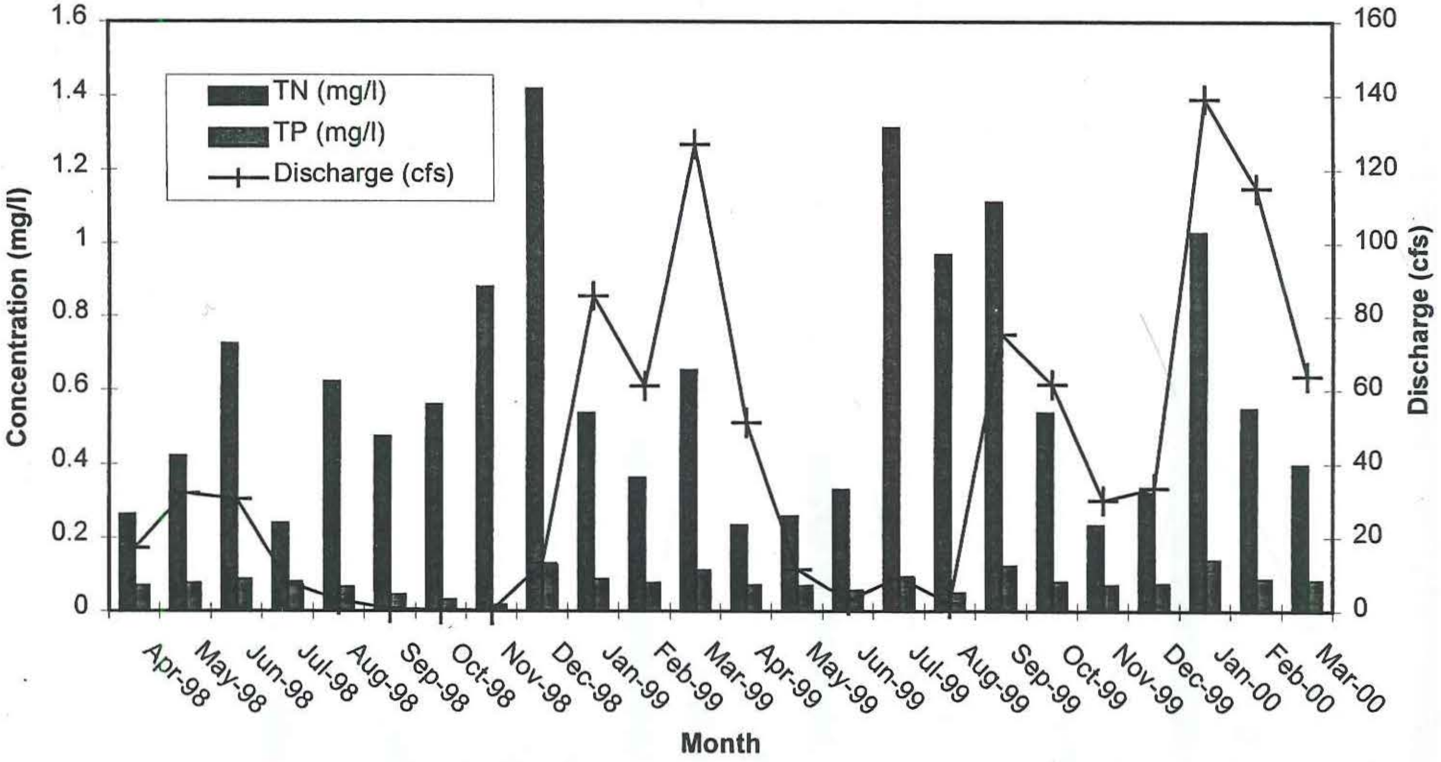


Fig 2-15. BasinSim outputs of stream flows and nutrient concentrations in Bush Mill Stream.

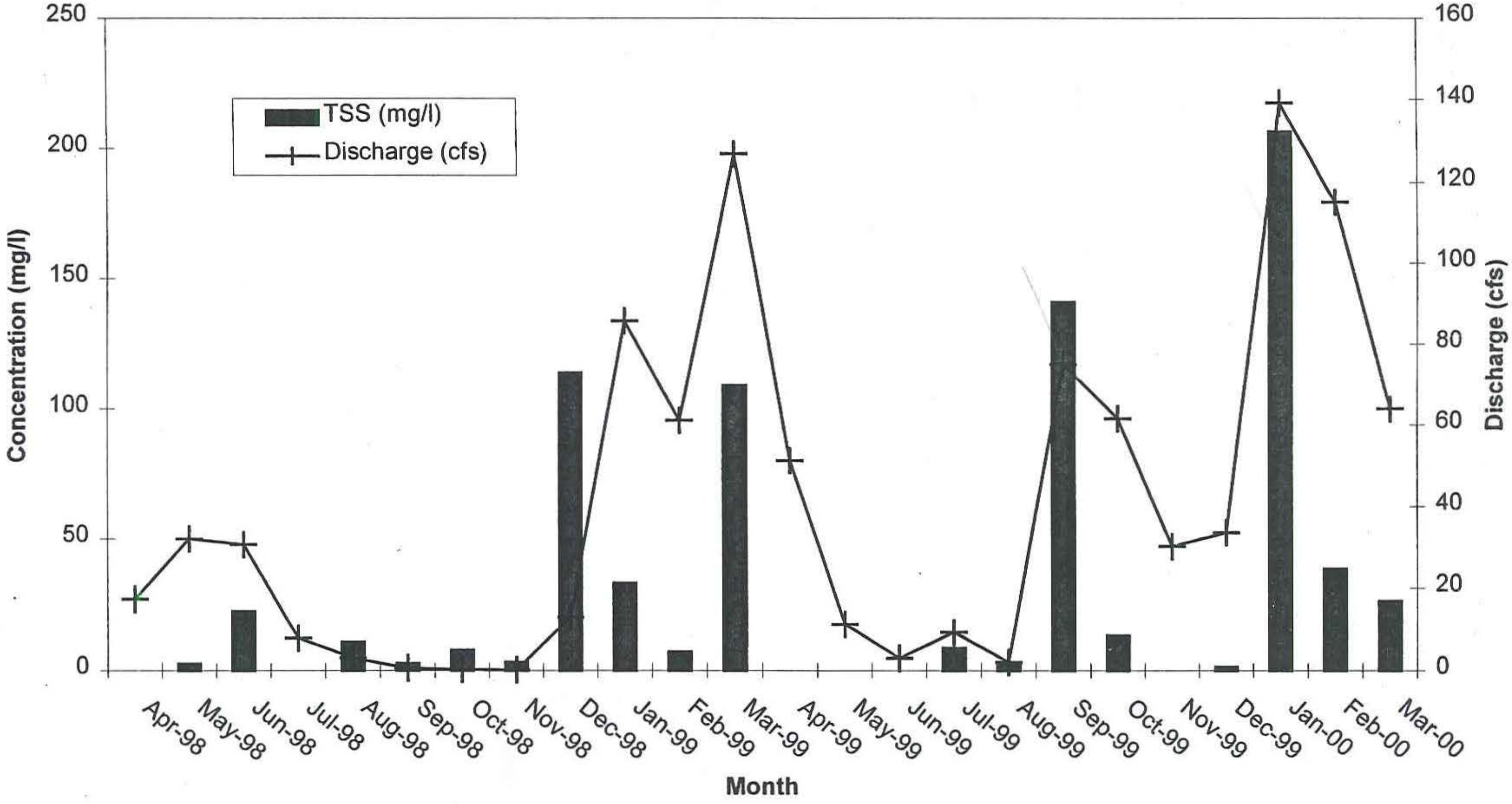


Fig 2-16. BasinSim outputs of stream flows and sediment concentrations in Bush Mill Stream.

III. Tidal Prism Water Quality Model

A. Background

The tidal prism water quality model (TPWQM) was first developed in late 1970 at the Virginia Institute of Marine Science as a tool to assist water quality management of small coastal basins (Kuo and Neilson, 1988). The model simulates the physical transport and biochemical processes in a water body, and predicts water quality conditions. The physical transport process is simulated in the model in terms of the tidal flushing concept (Ketchum, 1951).The implementation of the concept in numerical computation is straightforward, and thus ideal for application to small coastal basins which often have a high degree of branching.

The kinetic portion of the TPWQM was later expanded by Kuo and Park (1994) to describe more fully eutrophication processes and to be compatible with the modeling efforts in the Bay mainstem and major tributaries (Cerco and Cole, 1993). The number of water quality state variables was increased from 9 to 23.They are salinity, temperature, cyanobacteria, diatom, green algae, refractory and labile particulate organic carbon, dissolved organic carbon, refractory and labile particulate organic phosphorus, dissolved organic phosphorus, total phosphate, refractory and labile particulate organic nitrogen, dissolved organic nitrogen, ammonium nitrogen, nitrite-nitrate nitrogen, particulate biogenic silica, available silica, dissolved oxygen, chemical oxygen demand, total suspended solid, and fecal coliform bacteria. A new solution scheme (Park and Kuo, 1996) was also developed and used to replaced the old scheme in the model. The new scheme decouples the computation of kinetic processes from that of physical transport processes. This results in a simple and efficient computational procedure, and makes the future refinement of kinetic processes much easier.

The refined TPWQM has been successfully applied to the Lynnhaven River (Park et al., 1995) and four other small coastal basins in Virginia (Kuo et al., 1998). The model was also adopted by the Virginia Department of Environmental Quality for their use in determining wastewater discharge permits in the Virginia small coastal basins.

B. Model Application

To apply TPWQM, the Great Wicomico River was divided into 23 segments and 16 tributaries (Figure 3-1). The first segment is outside of the river in the Chesapeake Bay and sets the boundary conditions which are required for model simulation. The model also includes 2 side branches in Cockrell Creek, the largest tributary. The geometric data and tidal prism volumes of the model segments are listed in Table 3-1.

The model was run to simulate the river conditions from February 22, 1999 to March 31 2000, the period outputs from the watershed model are available (see previous chapter). The simulation of salinity distributions was examined first to investigate the model performance. The monthly stream flows from the watershed model outputs were linearly interpolated to provide the daily freshwater discharge data required for the tidal prism model. Each of the 15 sub-basins watershed model output was assigned to one or more segments of the TPWQM. The salinity data from the February 22, 1999 slackwater survey were used to generate the initial condition of the model run. The salinity data from the station at the river mouth, including those of the Chesapeake Program monitoring data at station CB5.4W, were interpolated to create time series data for the boundary condition.

The model calibration requires the adjustment of the returning ratio, the only calibration parameter for the physical transport process, until the model outputs of salinity distributions agree with field observations. Unfortunately the model calculated salinities are much lower than those observed, with all values of the returning ratio within the possible limit of 0 to 1.0. Past studies of the tidal prism model have demonstrated that the calculated salinity is relatively insensitive to the value of returning ratio between 0.1 to 0.5, and the value of 0.3 works well with all the small coastal basins of Virginia studied to date(Kuo et al., 1998).The model results using the value of 0.3 for the returning ratio are compared with field data in Figures 3-2. These figures show that the model severely under predicts the salinity level throughout the river, and no adjustment of the calibration parameter can bring the model predictions close to field observations.

Salinity distributions in an estuary are controlled by the salinity level at its mouth, tidal mixing, and the amount of freshwater inflow to the system. In applying the tidal prism model to the Great Wicomico River, the first two are obtained from direct field observation, and the last one is derived from the outputs of the watershed model, BasinSim. Therefore it may be concluded that the calculated stream flows from BasinSim are much higher than those comparable with observed salinity distribution in the river. BasinSim computes surface runoff and groundwater flow, and sums them together as stream flow. When using them for input to the tidal prism model, there is an unresolved question as to whether the groundwater flow enters the estuary in the same segment as the surface runoff. In the case of the Great Wicomico River, it is unknown if the groundwater from the drainage basin may directly discharge into the Chesapeake Bay and not directly into the river. A model sensitivity run was conducted using only the surface runoff portion of the stream flow as inputs of the freshwater discharge in the tidal prism model. The calculated salinity distributions are compared with field observations in Figures 3-3.

Figures 3-3 show that the model results are much improved, though they are still lower than observed salinities. Particularly, the model calculated salinity at station M6 (Fig. 3-3 (a)) starts to decrease sharply around Julian day 230, in response to a big runoff event predicted by BasinSim due to a rainfall event in September. However the field data indicate that salinity at the station started to decrease at a later date and the decrease is not as pronounced. This may result from overestimation of runoff by the watershed model as well as the interpolation of monthly flows. There is a mismatch of time scales between the tidal prism model and the watershed model. Figures 3-3 also indicate that the model results for Cockrell Creek agree with observations much better than those in the mainstem Great Wicomico River. The slight under prediction by the model in Cockrell Creek may be attributed to the under prediction at its mouth in the mainstem. The fact that the precipitation data required for the BasinSim input was measured at Reedsville in the Cockrell Creek sub-basin may explain the better simulation there. It is uncertain whether the precipitation data is representative of the upper Great Wicomico watershed, which contributes the most runoff to the mainstem of the river. Because of the uncertainty in the stream flows calculated by the watershed model, the eutrophication portion of the TPWQM was not calibrated.

Table 3-1. Geometric and Tidal Prism Data of Model Segments

Segment Number	Distance from River Mouth (km)	Volume at High Tide ($10^6 m^3$)	Tidal Prism ($10^6 m^3$)	Depth at Mean Tide (m)
1	---	---	8.168	---
2	0.84	7.833	7.120	3.21
3	1.70	7.120	5.505	3.19
4	2.74	5.558	4.705	3.33
5	3.34	4.736	4.315	4.70
6	4.21	4.340	3.868	4.19
7	5.37	3.883	3.382	3.64
8	6.30	3.421	3.031	3.87
9	6.95	3.036	2.805	4.44
10	7.63	2.823	2.569	4.33
11	8.42	2.575	2.288	4.07
12	9.25	2.310	1.968	3.83
13	9.92	1.974	1.708	3.83
14	10.92	1.722	1.398	3.03
15	11.77	1.414	1.137	2.56
16	12.44	1.151	0.928	2.31
17	13.16	0.941	0.754	1.88
18	13.81	0.759	0.616	1.83
19	14.43	0.624	0.506	1.79
20	15.03	0.508	0.407	1.59
21	15.82	0.408	0.296	1.09
22	17.12	0.458	0.079	0.80
23	18.42	0.149	0.000	0.48
Branch #1 Harveys Creek				
1	---	---	0.112	---
2	0.92	0.250	0.047	1.33
3	1.84	0.247	0.000	1.33
Branch #2 Tewles Creek				
1	---	---	0.023	---
2	0.37	0.024	0.011	0.47
3	0.69	0.021	0.000	0.47
Branch #3 Cockrell Creek				
1	---	---	1.072	---
2	0.46	1.094	0.945	2.76
3	0.86	0.951	0.836	2.76
4	1.22	0.816	0.727	2.76
side branch	---	0.100	0.030	1.00
5	1.81	0.738	0.642	2.45
6	2.47	0.647	0.553	2.30

7	3.40	0.653	0.323	1.31
side branch	---	0.500	0.100	1.20
8	4.50	0.540	0.200	1.31
9	5.70	0.800	0.000	1.31
Branch #4 Cranes Creek				
1	---	---	0.344	---
2	0.38	0.350	0.289	2.00
3	1.20	0.733	0.150	1.52
4	2.53	0.700	0.000	1.52
Branch #5 Reason Creek				
1	---	---	0.107	---
2	0.92	0.484	0.000	1.39
Branch #6 Whays Creek				
1	---	---	0.125	---
2	0.43	0.125	0.097	1.39
3	1.13	0.218	0.052	1.39
4	1.93	0.436	0.000	1.39
Branch #7 Gougher Creek				
1	---	---	0.073	---
2	1.01	0.327	0.000	1.394
Branch #8 Warehouse Creek				
1	---	---	0.099	---
2	0.48	0.101	0.071	1.09
3	0.83	0.073	0.051	1.09
4	1.70	0.182	0.000	1.09
Branch #9 Horn Harbor Creek				
1	---	---	0.066	---
2	0.45	0.067	0.041	0.79
3	1.20	0.151	0.000	1.26
Branch #10 Barrett Creek				
1	---	---	0.125	---
2	0.60	0.300	0.062	1.40
3	1.15	0.546	0.000	1.40
Branch #11 Tipers Creek				
1	---	---	0.124	---
2	0.47	0.124	0.092	1.25
3	0.82	0.092	0.069	1.25
4	1.84	0.269	0.000	1.25
Branch #12 Coles Creek				
1	---	---	0.033	---
2	1.06	0.189	0.000	1.25
Branch #13 Balls Creek				
1	---	---	0.185	---
2	0.90	0.310	0.090	1.40

3	1.89	0.300	0.000	1.40
Branch #14 Betts Mill Creek				
1	---	---	0.098	---
2	0.53	0.099	0.060	0.80
3	1.38	0.159	0.000	0.80
Branch #15 Black Wells Creek				
1	---	---	0.026	---
2	0.46	0.053	0.000	0.59
Branch #16 Crabbe Mill Creek				
1	---	---	0.088	---
2	0.78	0.088	0.038	0.50
3	1.38	0.068	0.000	0.50

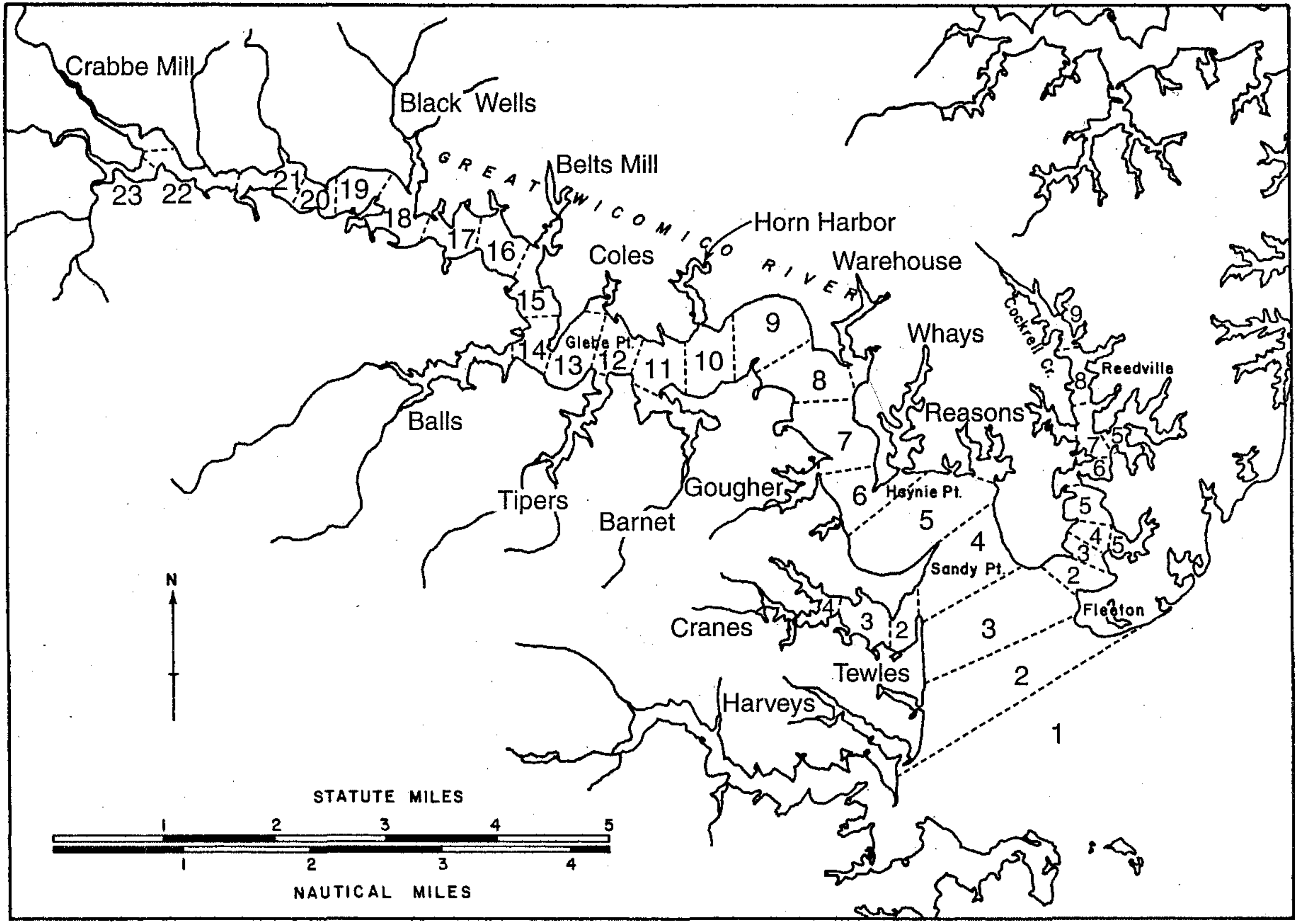


Fig. 3-1. Segmentation of the Great Wicomico River for tidal prism model application

Fig. 3-2. Comparisons of observed salinity data (+) with model results (solid line) using total stream flows predicted by BasinSim.

(a), (b). Temporal variations at station M6 (in mainstream GWR) and C4 (in Cockrell Creek)

(c) - (p). Spatial distributions in the Great Wicomico River and Cockrell Creek

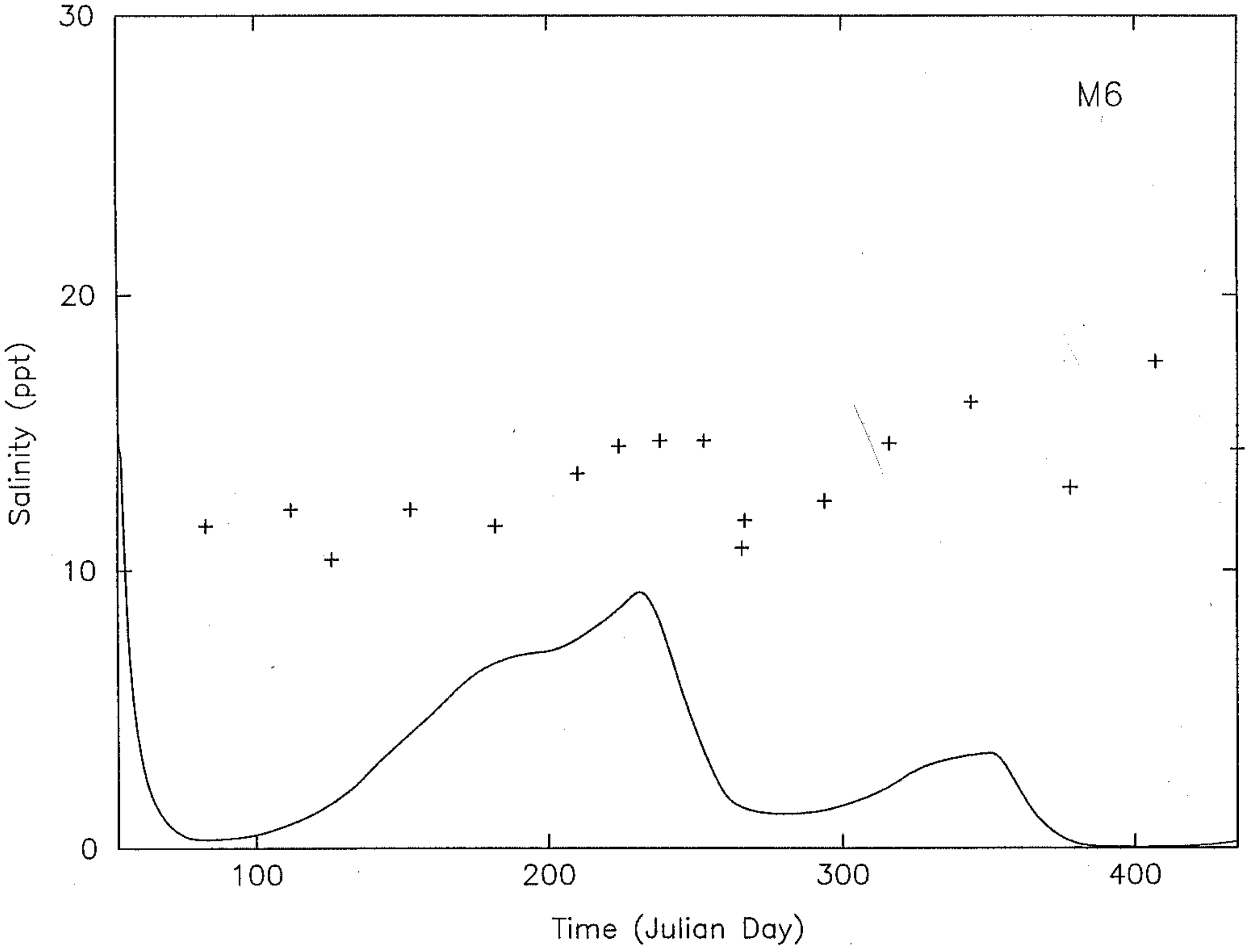


Fig. 3-2 (a)

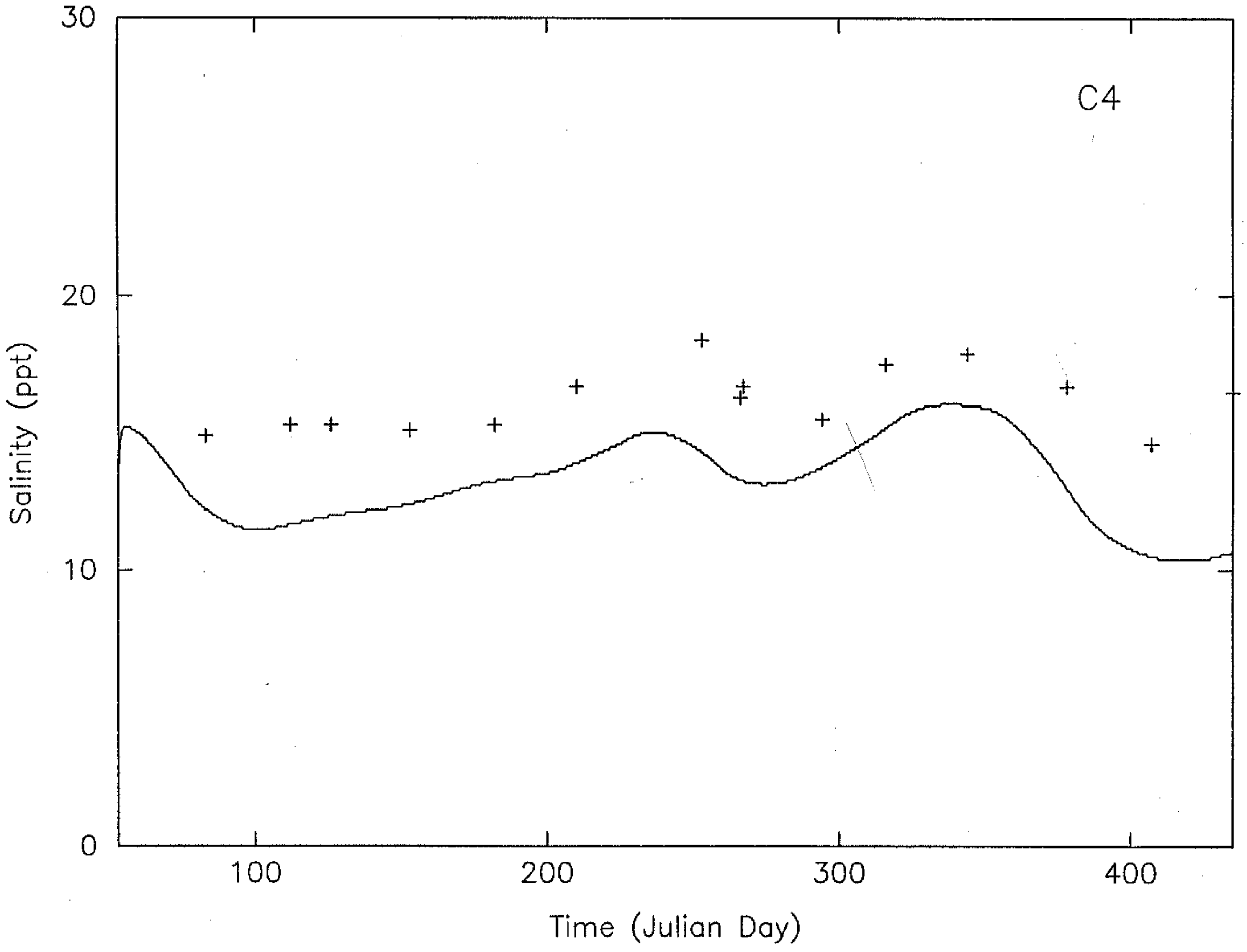


Fig. 3-2 (b)

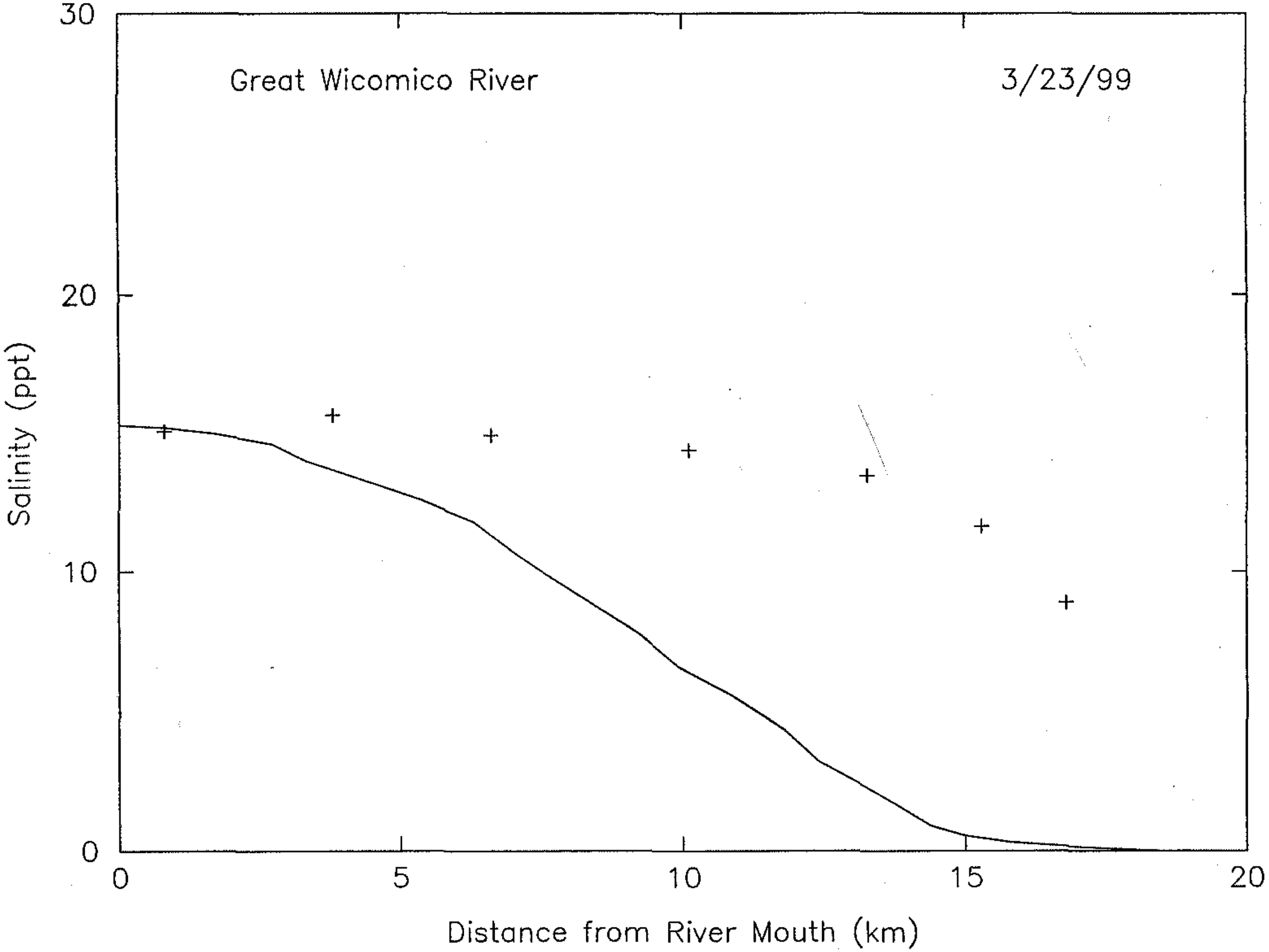

Great Wicomico River
3/23/99
Salinity (ppt)
30
20
10
0
0
5
10
15
20
Distance from River Mouth (km)

Fig. 3-2 (c)

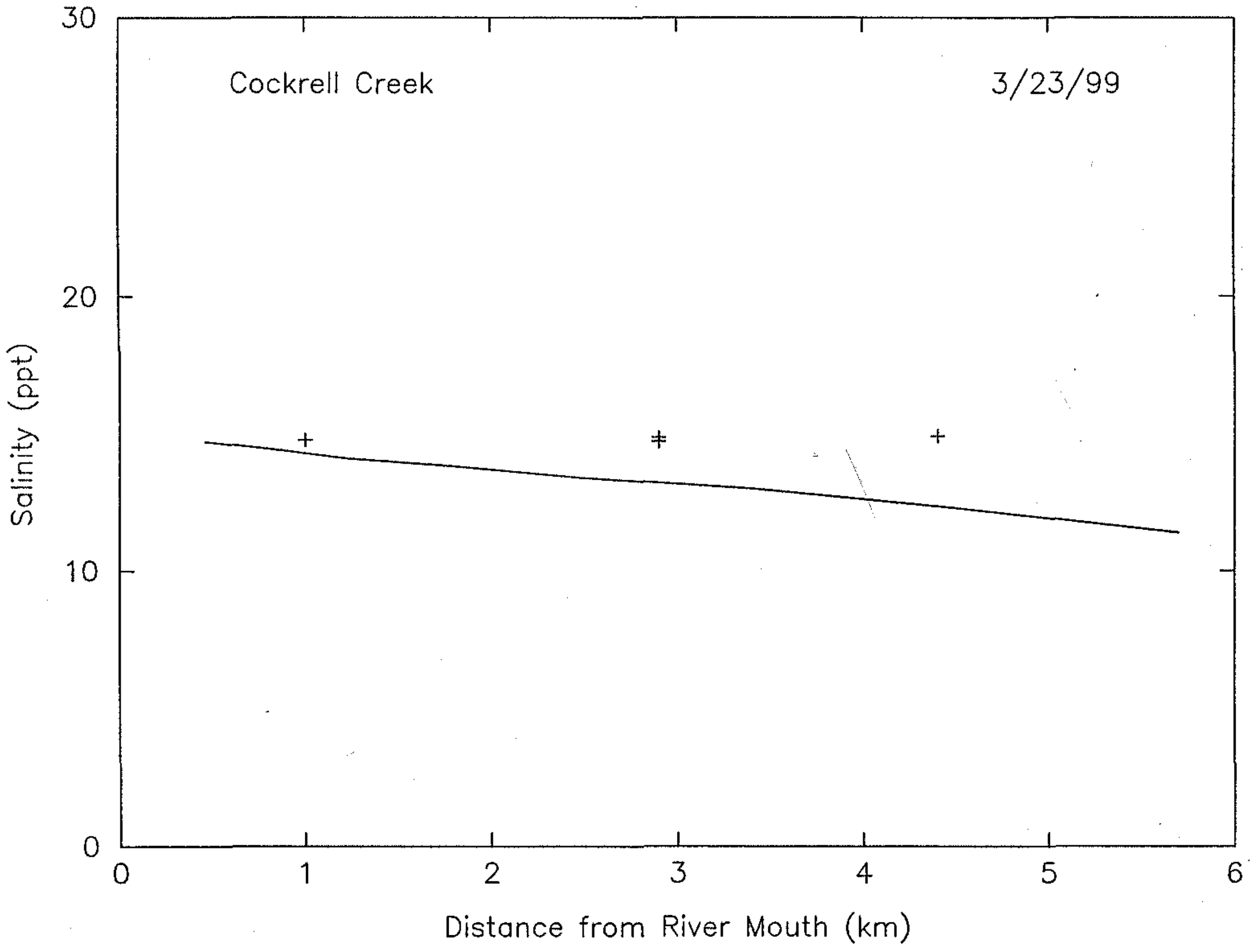

Cockrell Creek
3/23/99
30
20
10
0
Salinity (ppt)
0
1
2
3
4
5
6
Distance from River Mouth (km)

Fig. 3-2 (d)

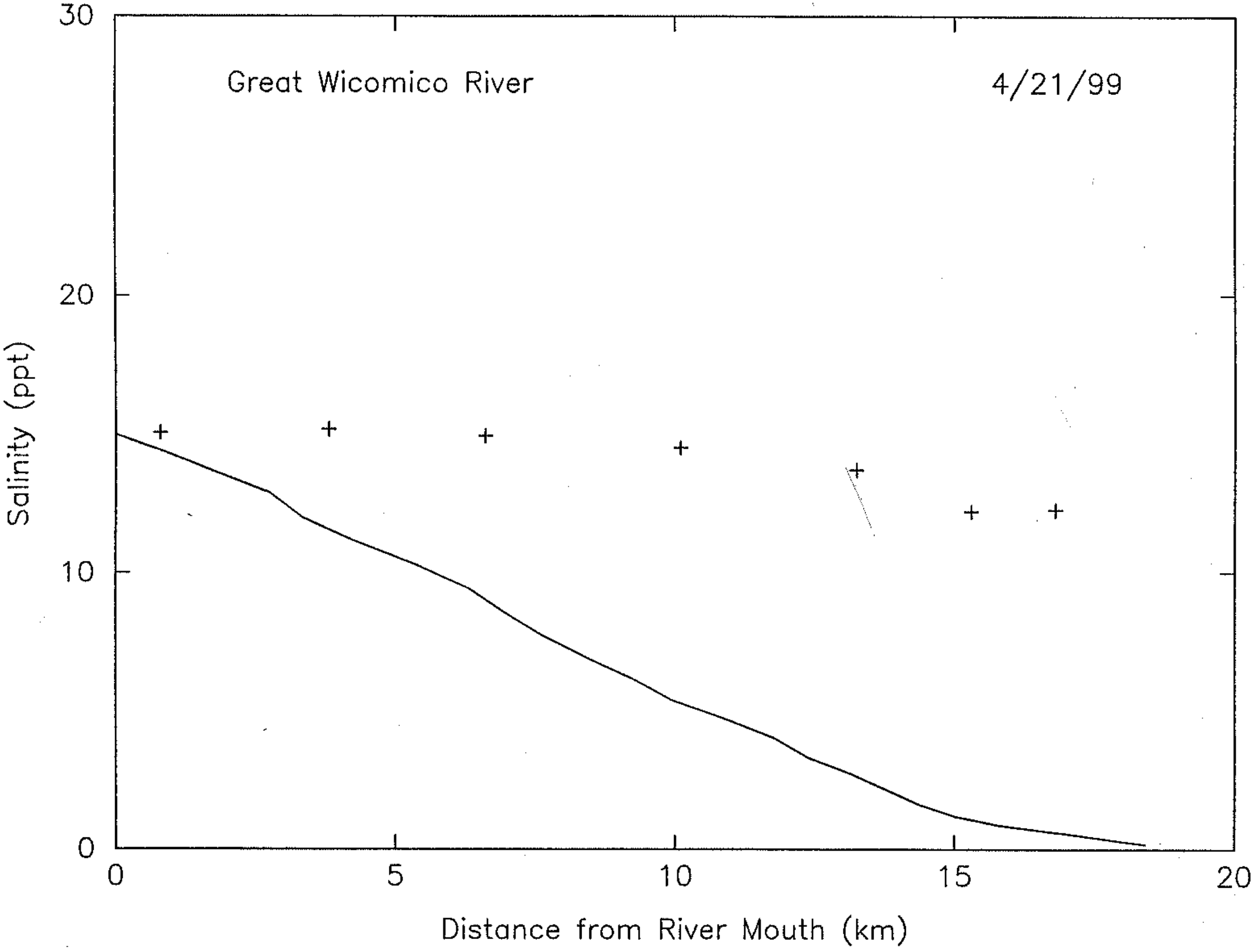

Great Wicomico River
4/21/99
Salinity (ppt)
Distance from River Mouth (km)
0
10
20
30
0
5
10
15
20

Fig. 3-2 (e)

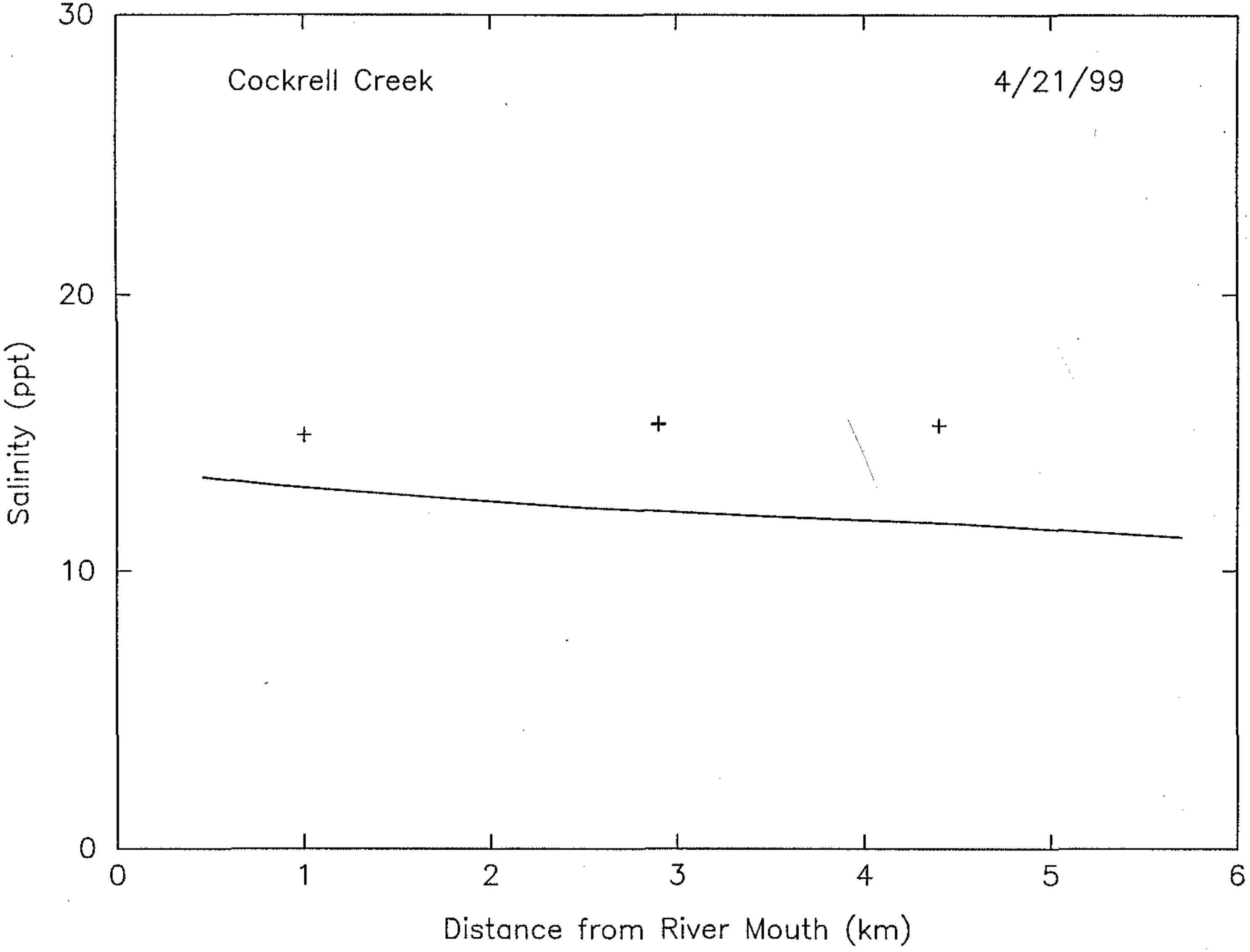

Cockrell Creek
4/21/99
30
20
10
0
Salinity (ppt)
0
1
2
3
4
5
6
Distance from River Mouth (km)

Fig. 3-2 (f)

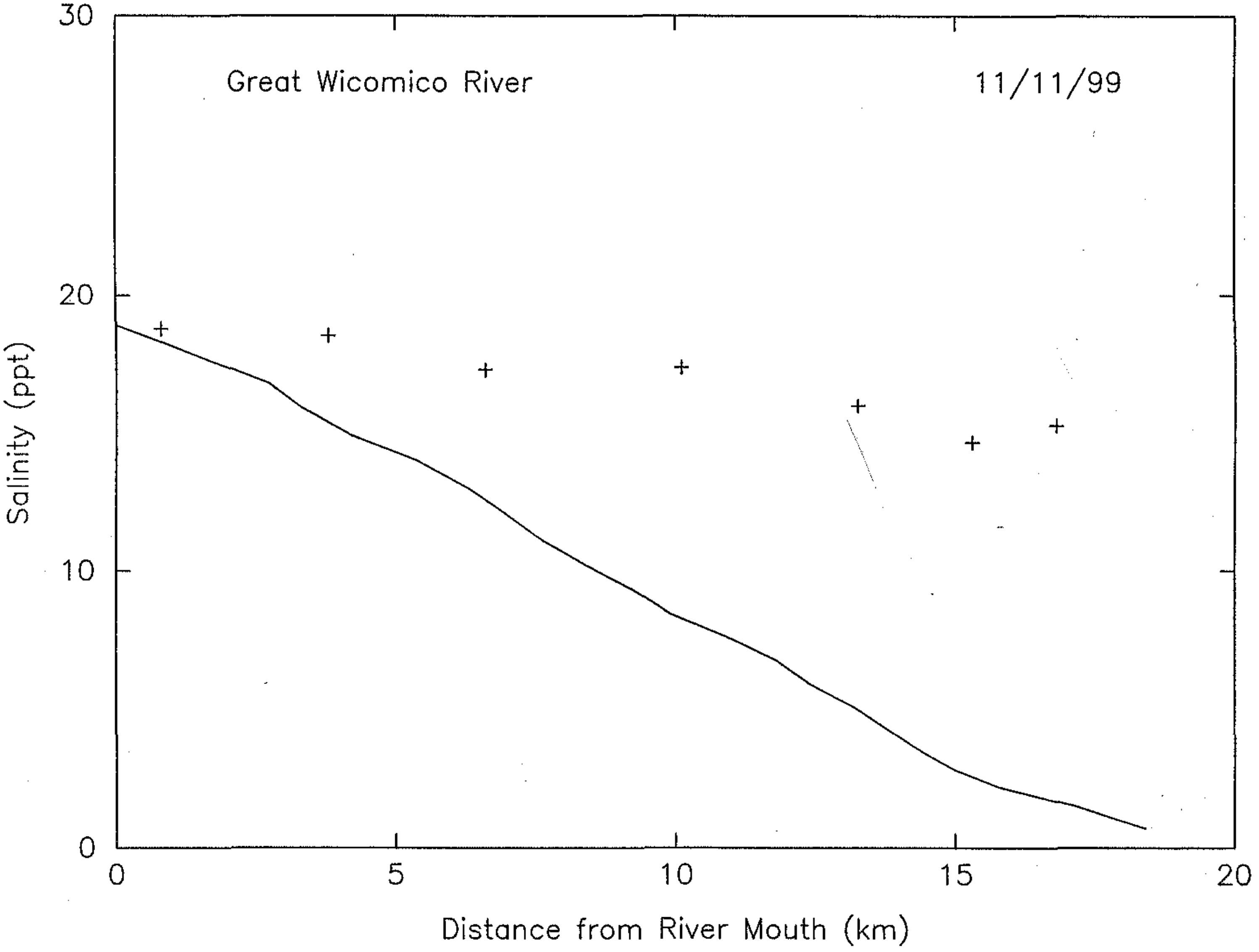

Great Wicomico River
11/11/99
Salinity (ppt)
30
20
10
0
0
5
10
15
20
Distance from River Mouth (km)

Fig. 3-2 (g)

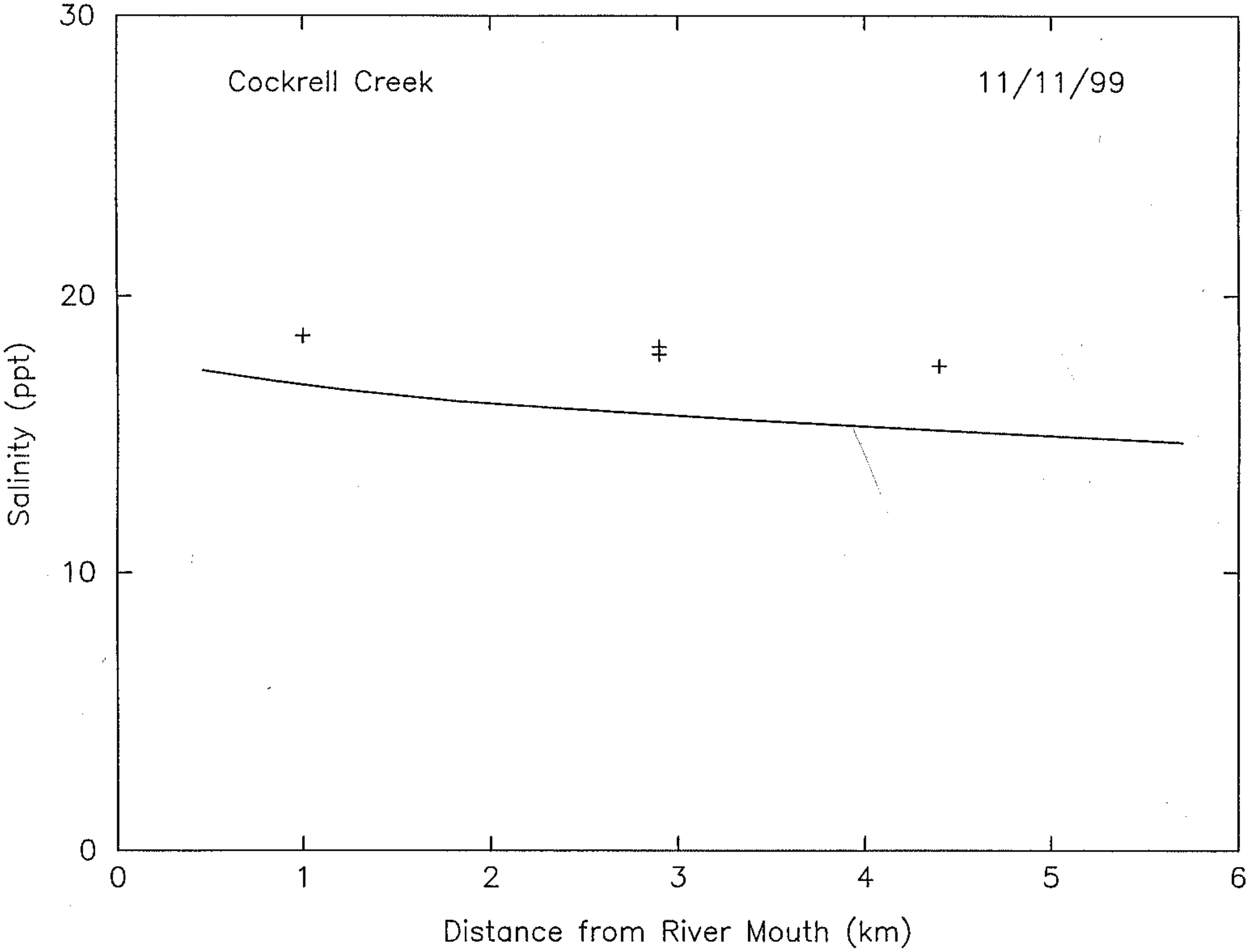

Cockrell Creek
11/11/99
Salinity (ppt)
30
20
10
0
0
1
2
3
4
5
6
Distance from River Mouth (km)

Fig. 3-2 (h)

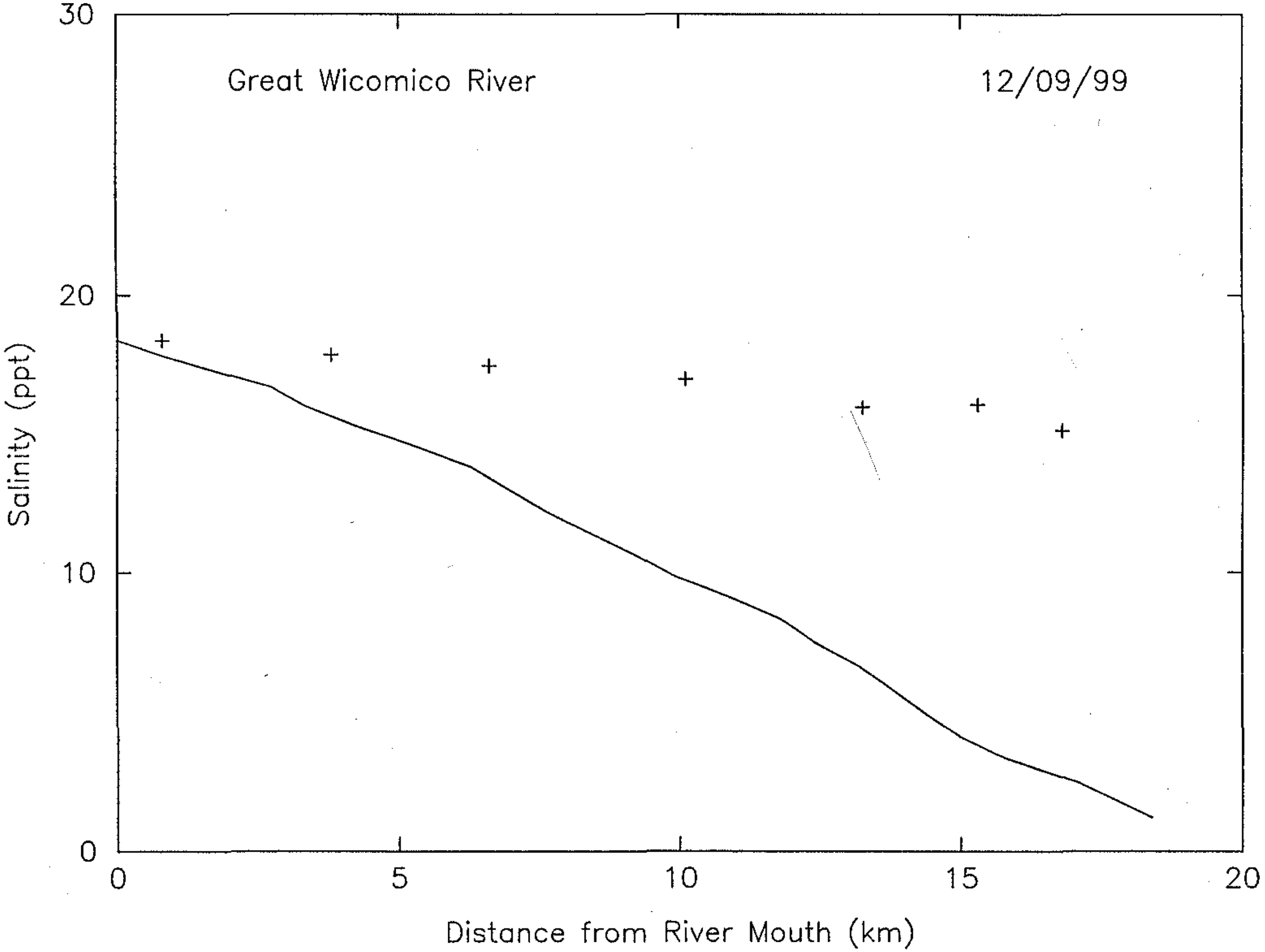

Great Wicomico River
12/09/99
Salinity (ppt)
Distance from River Mouth (km)
30
20
10
0
0
5
10
15
20

Fig. 3-2 (i)

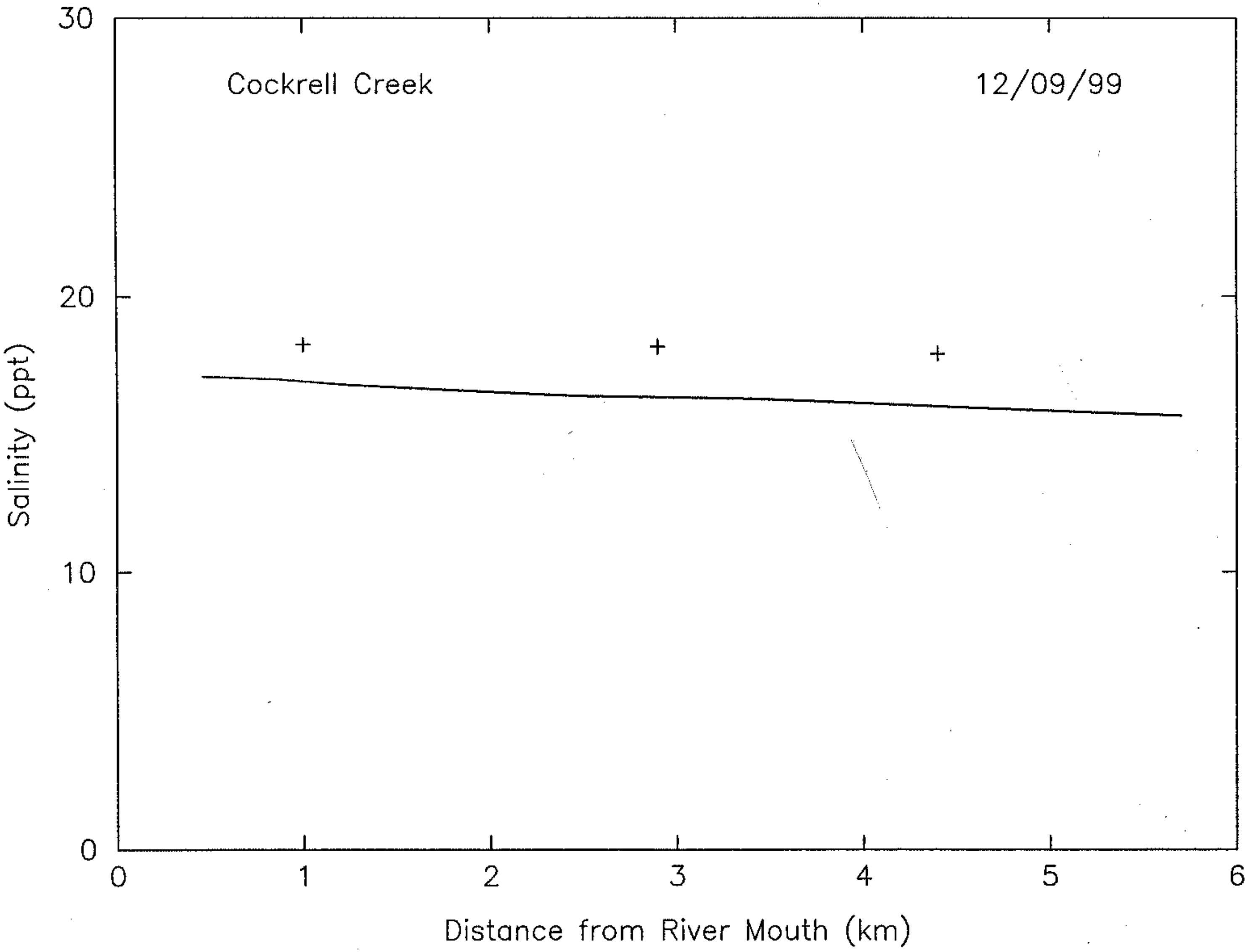

Cockrell Creek
12/09/99
Salinity (ppt)
30
20
10
0
0
1
2
3
4
5
6
Distance from River Mouth (km)

Fig. 3-2 (j)

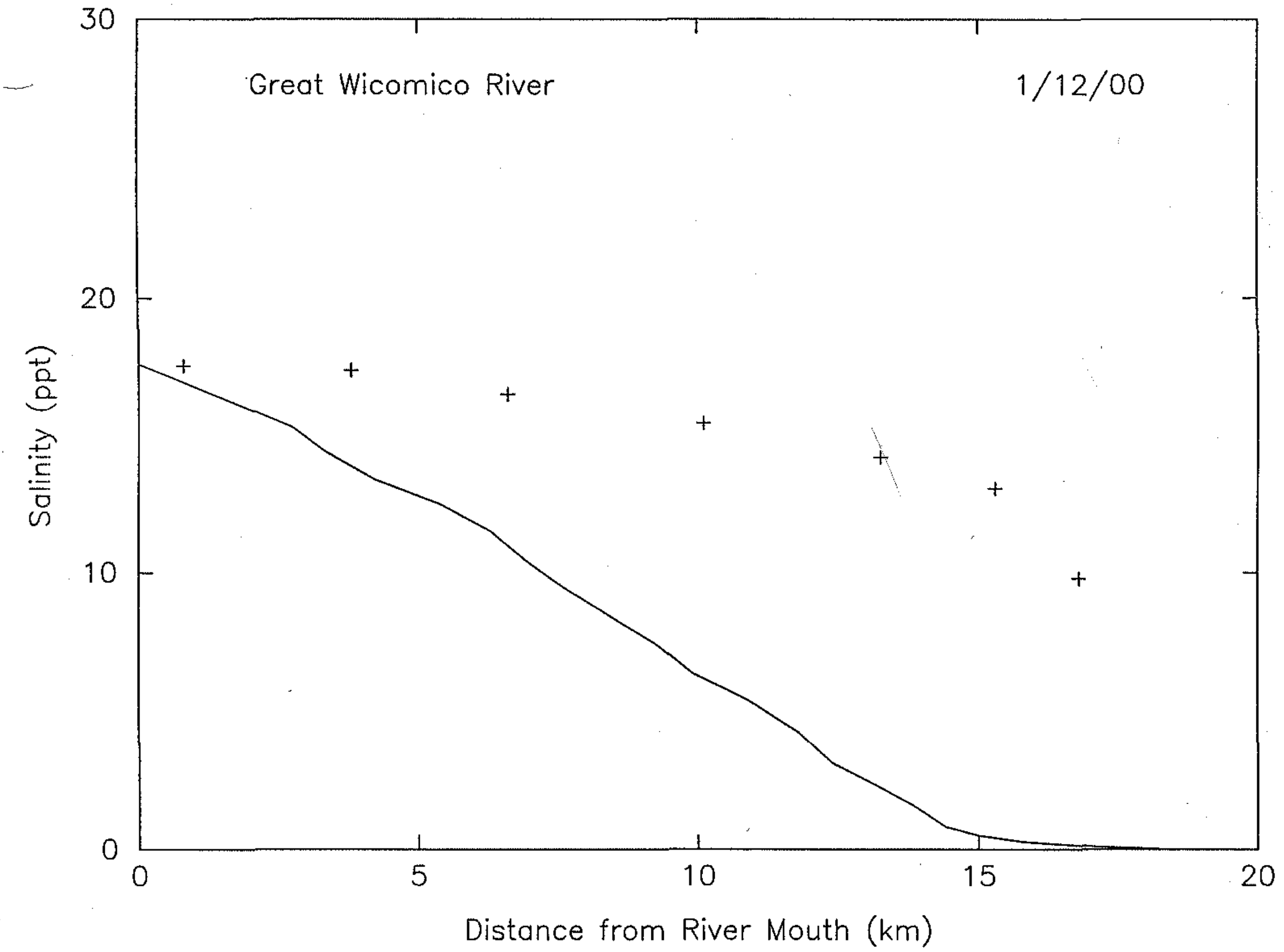

Great Wicomico River
1/12/00
Salinity (ppt)
30
20
10
0
0
5
10
15
20
Distance from River Mouth (km)

Fig. 3-2 (k)

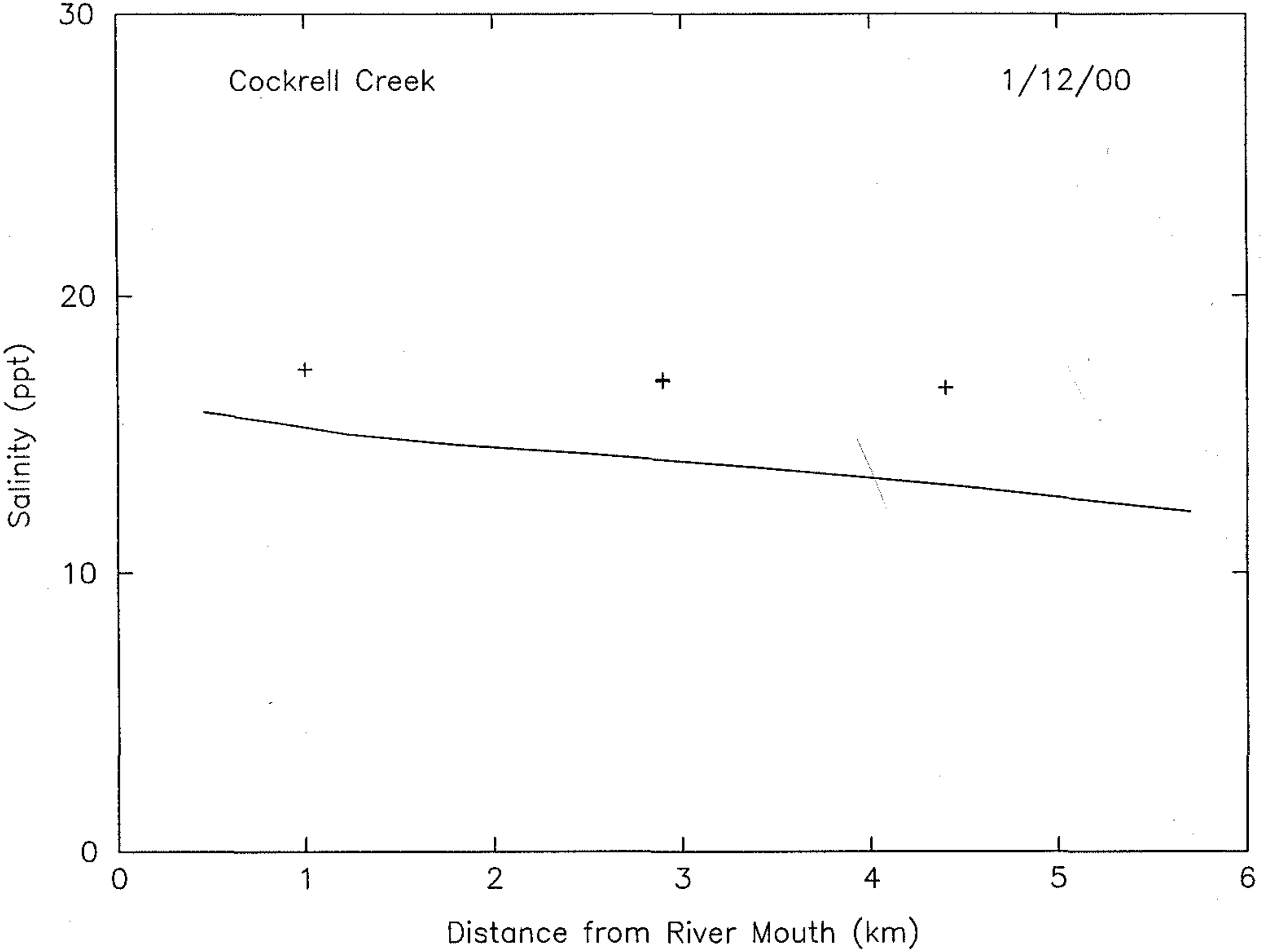

Cockrell Creek
1/12/00
Salinity (ppt)
30
20
10
0
0
1
2
3
4
5
6
Distance from River Mouth (km)

Fig. 3-2 (l)

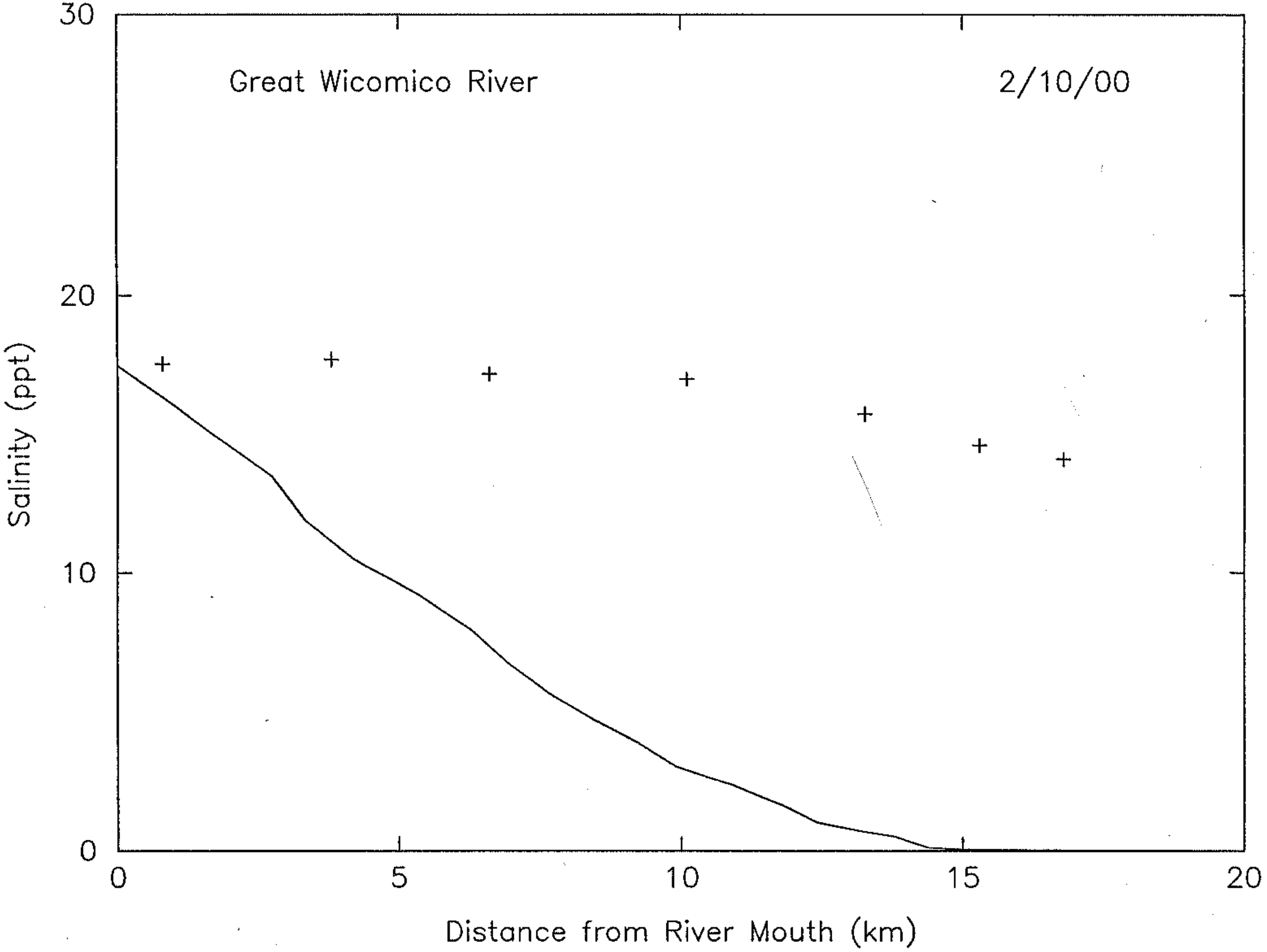

Great Wicomico River
2/10/00
Salinity (ppt)
30
20
10
0
0
5
10
15
20
Distance from River Mouth (km)

Fig. 3-2 (m)

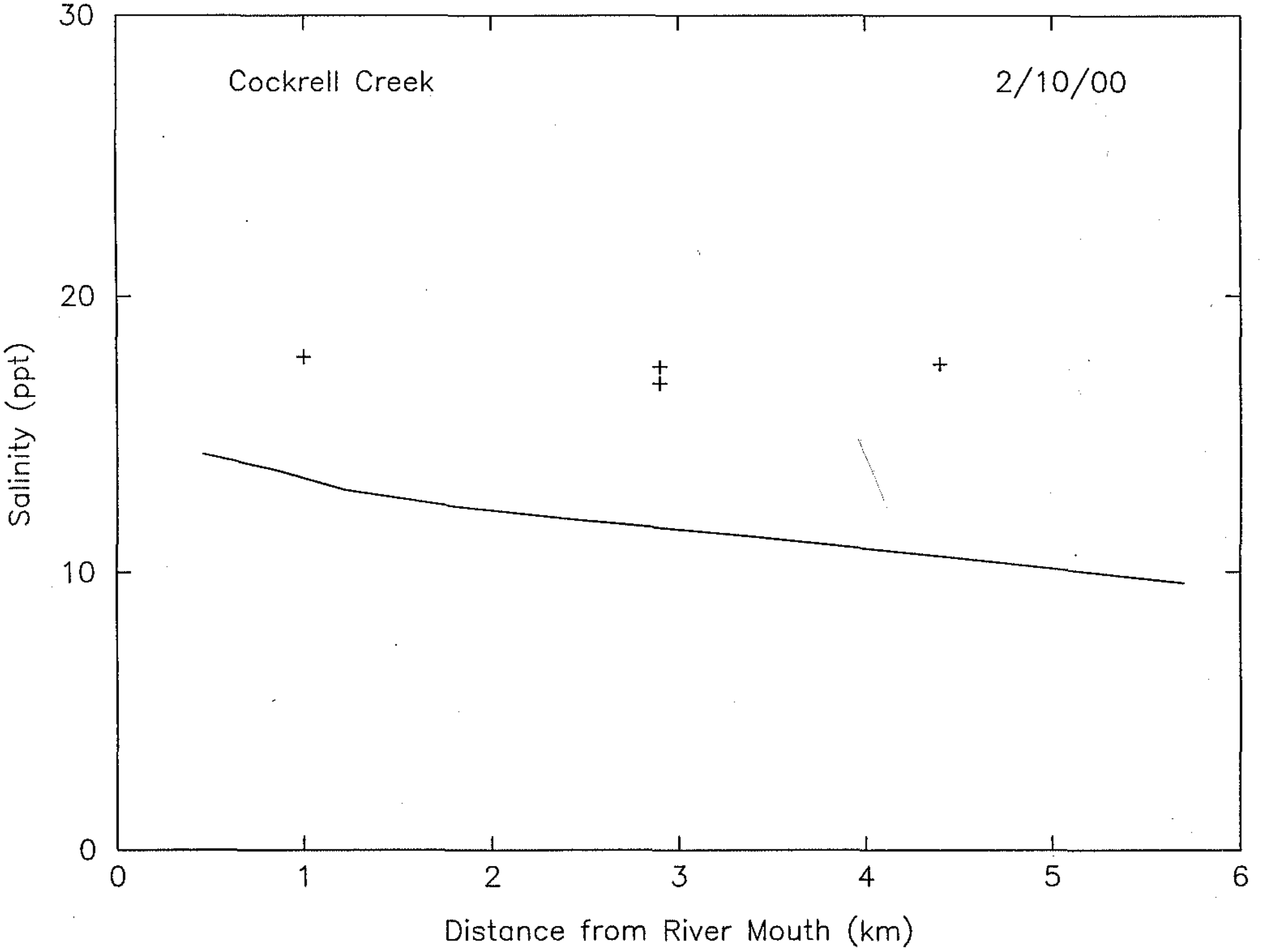

Cockrell Creek
2/10/00
Salinity (ppt)
30
20
10
0
0
1
2
3
4
5
6
Distance from River Mouth (km)

Fig. 3-2 (n)

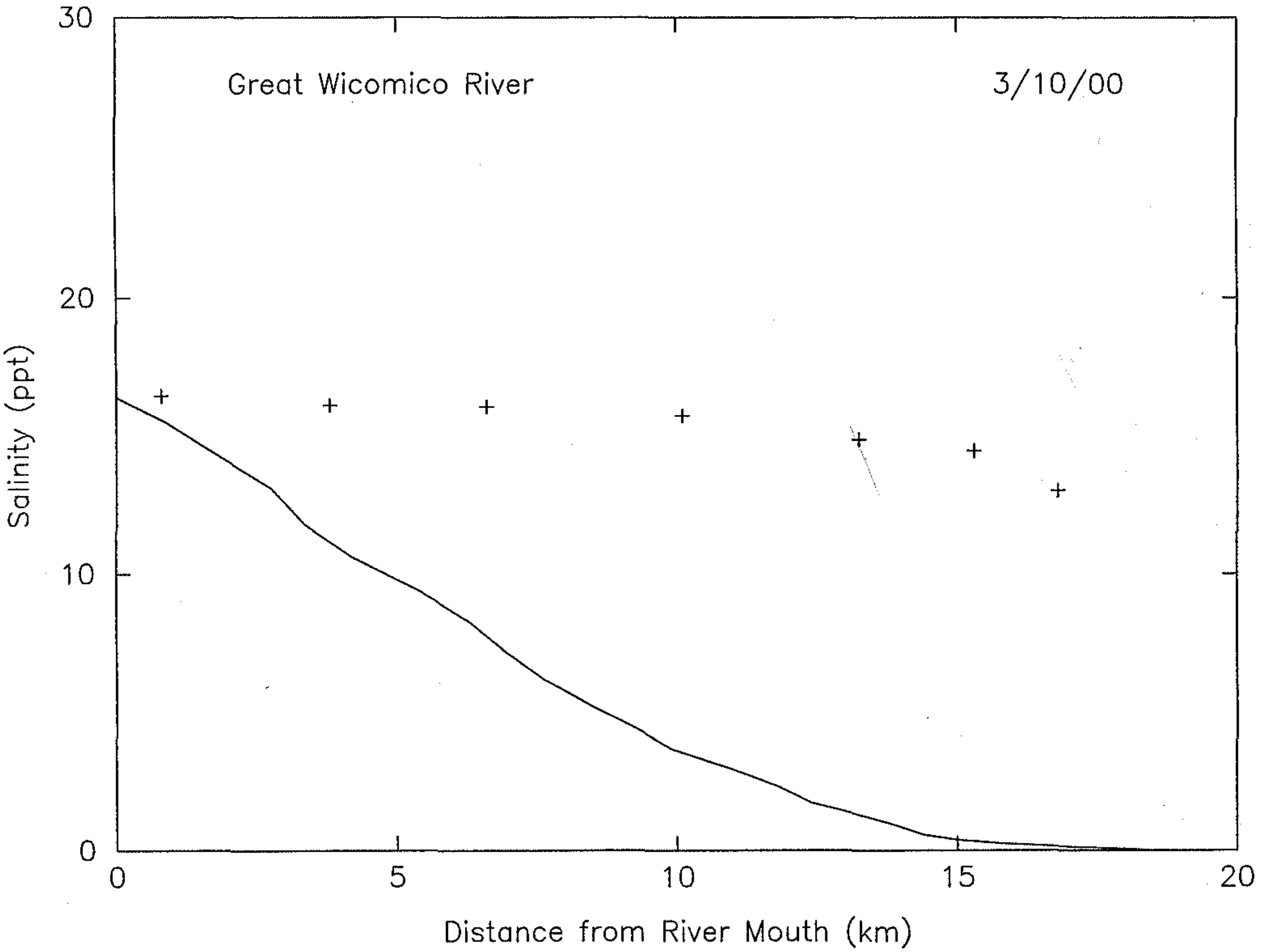

Great Wicomico River
3/10/00
Salinity (ppt)
30
20
10
0
0
5
10
15
20
Distance from River Mouth (km)

Fig. 3-2 (o)

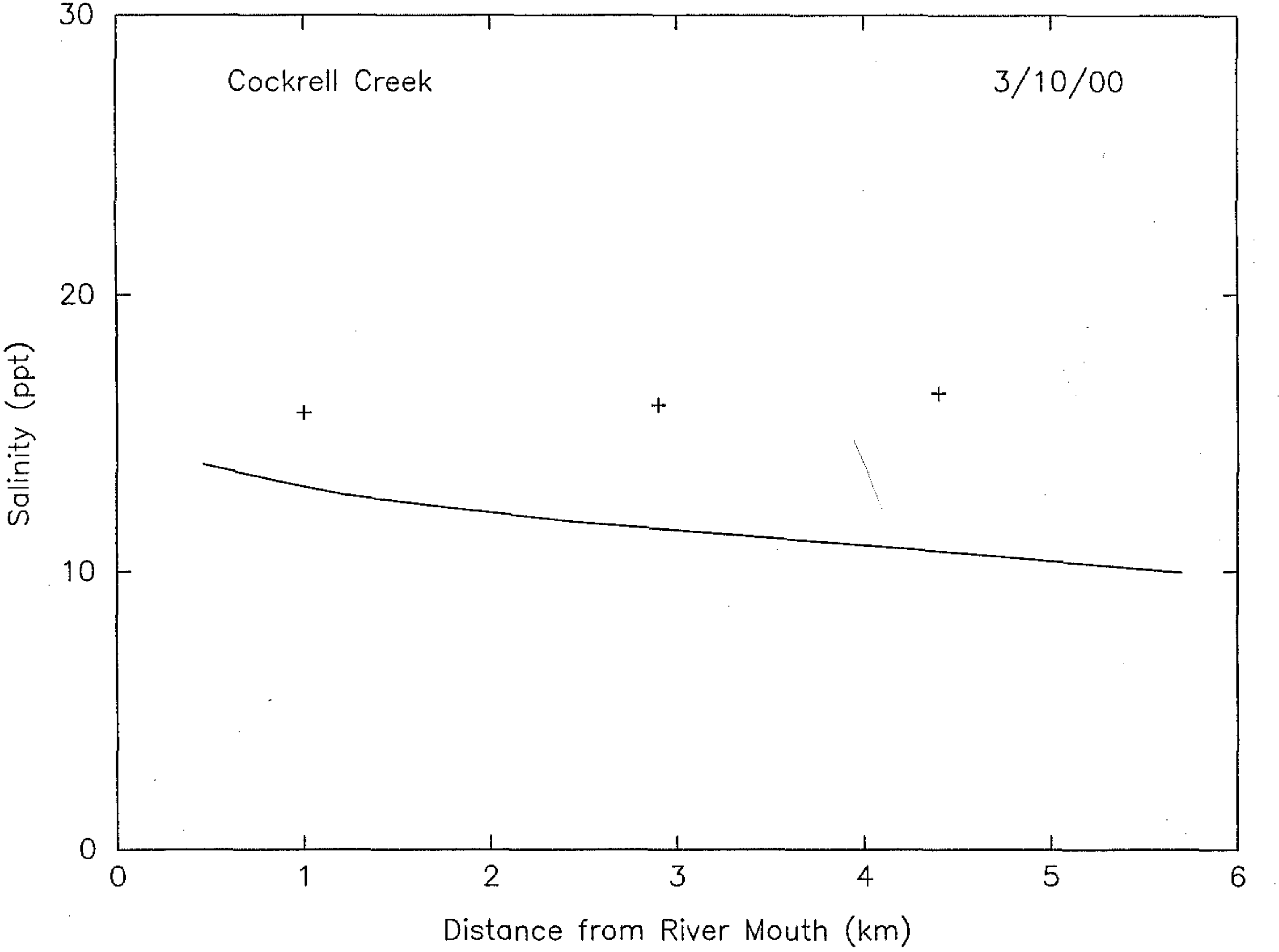

Cockrell Creek
3/10/00
Salinity (ppt)
30
20
10
0
0
1
2
3
4
5
6
Distance from River Mouth (km)

Fig. 3-2 (p)

Fig. 3-3. Comparisons of observed salinity data (+) with model results (solid line) using only the surface runoff predicted by BasinSim.

(a), (b). Temporal variations at station M6 (in mainstream GWR) and C4 (in Cockrell Creek)

(c) - (p). Spatial distributions in the Great Wicomico River and Cockrell Creek

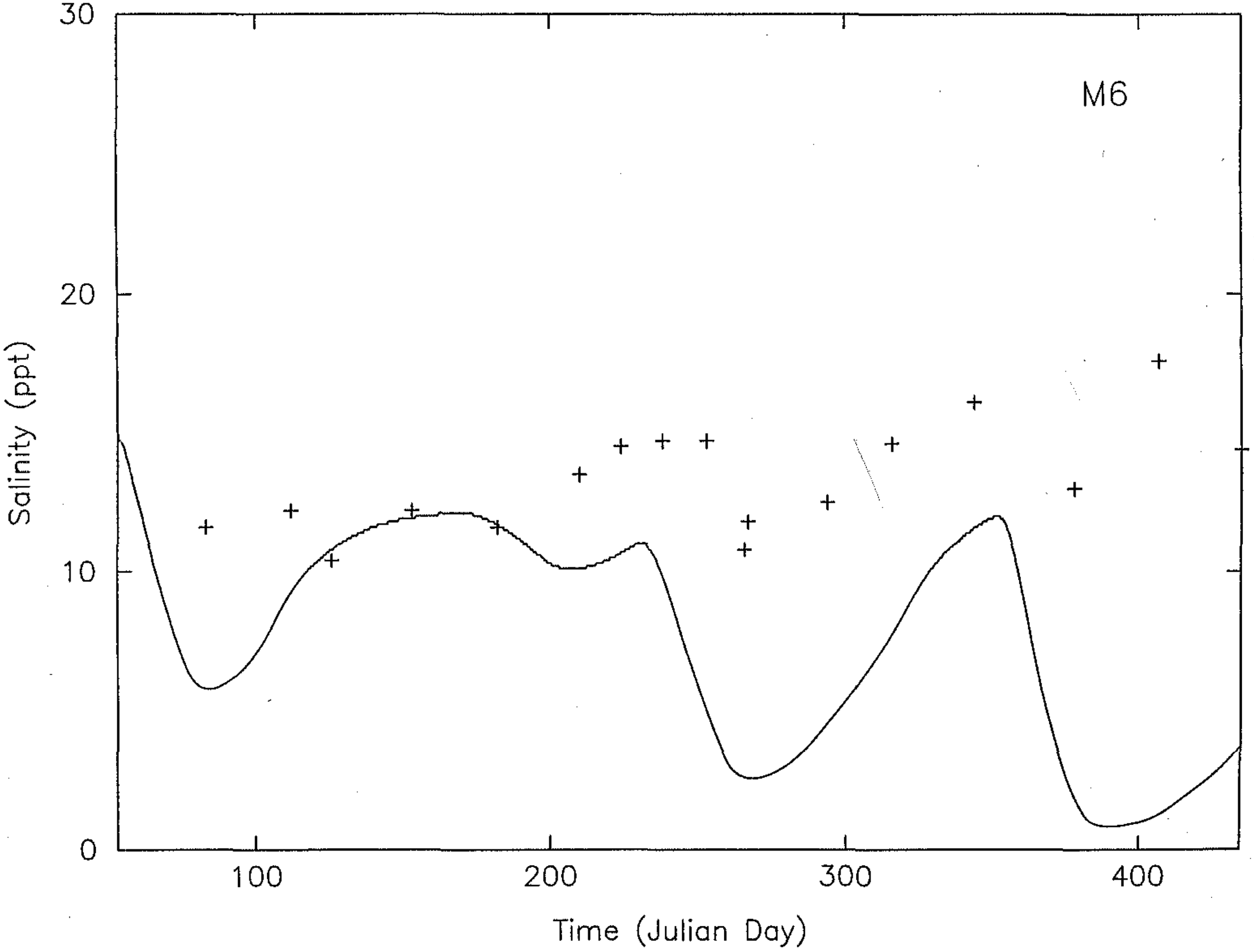


Fig. 3-3 (a)

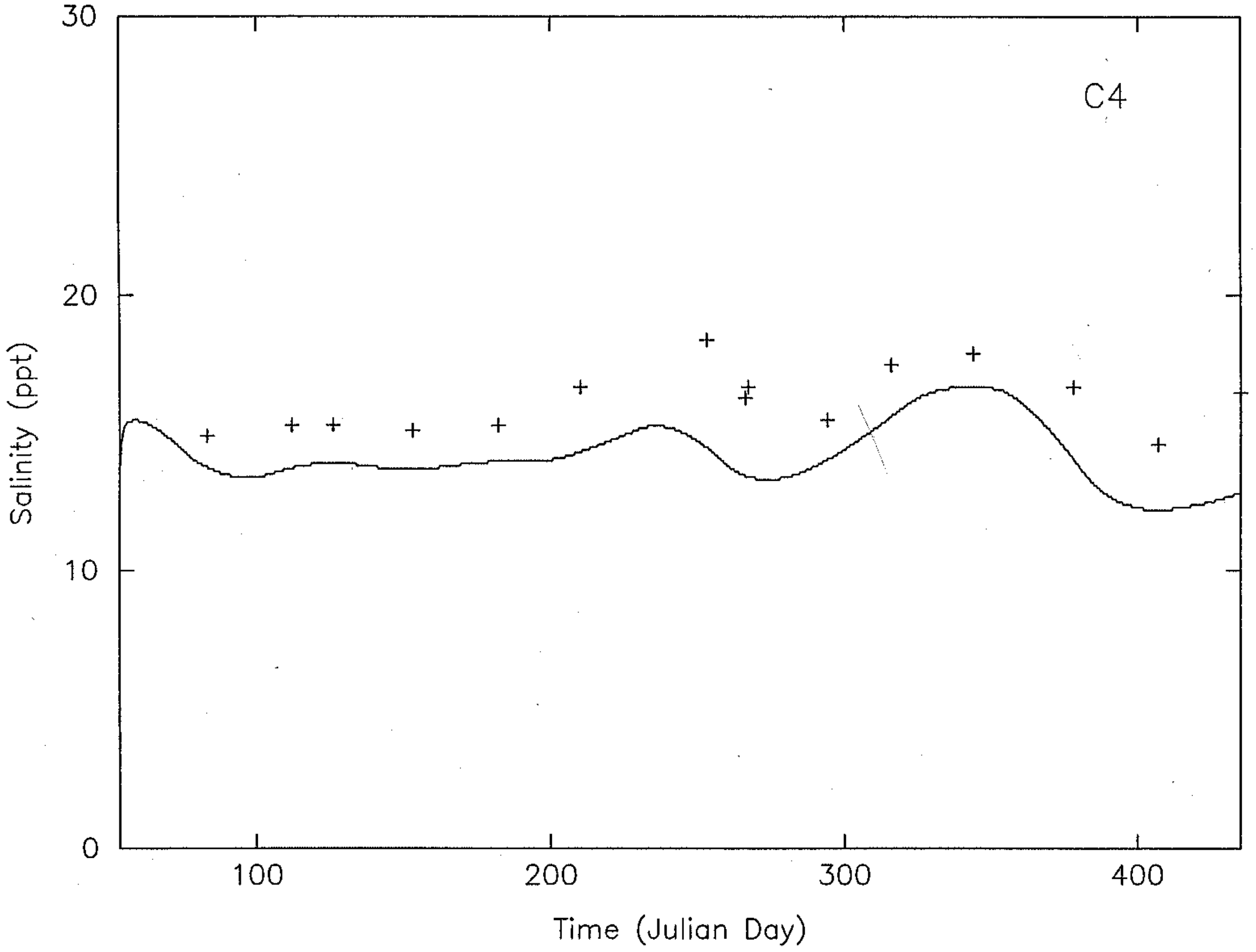


Fig. 3-3 (b)

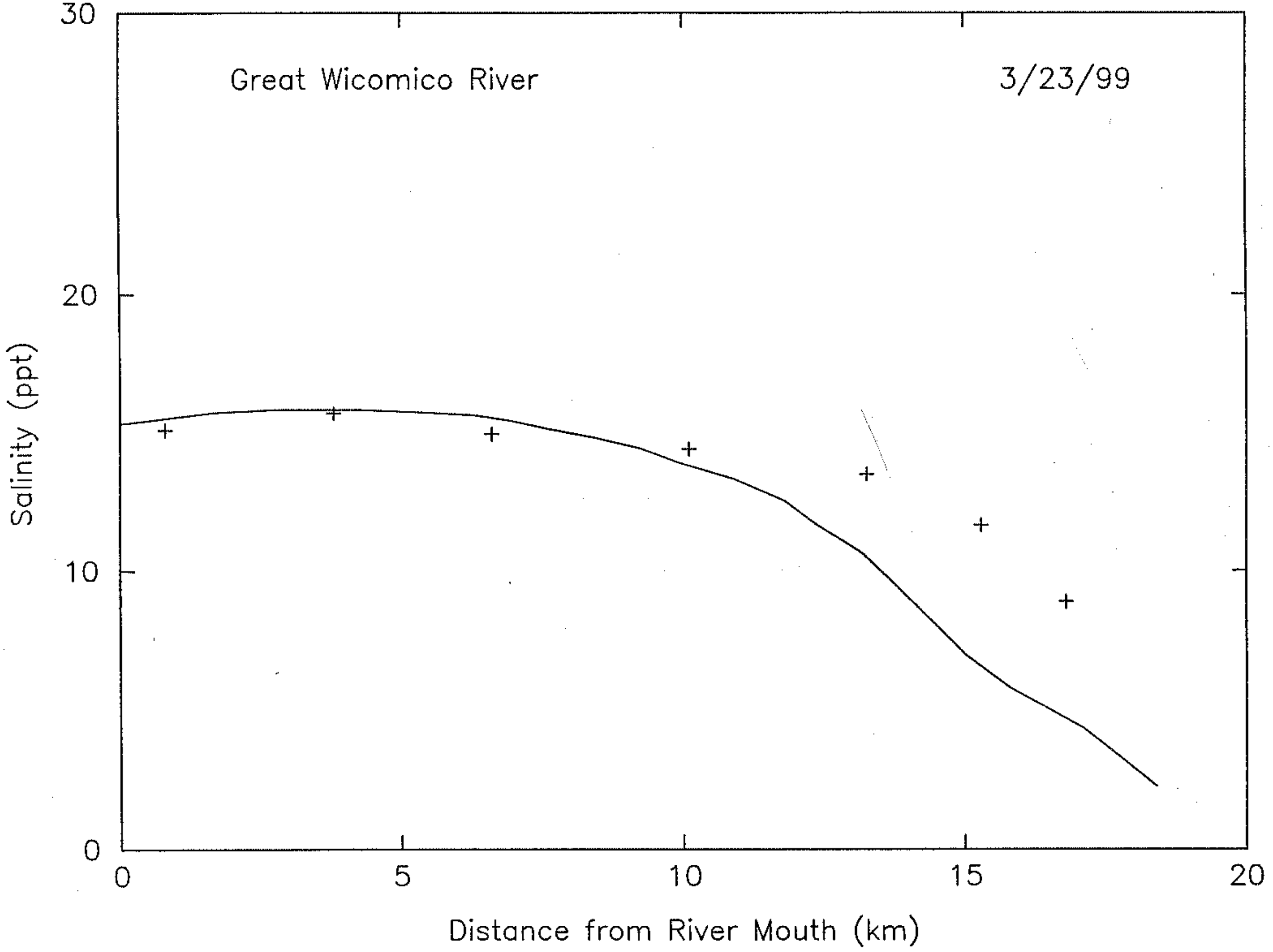

Great Wicomico River
3/23/99
Salinity (ppt)
30
20
10
0
0
5
10
15
20
Distance from River Mouth (km)

Fig. 3-3 (c)

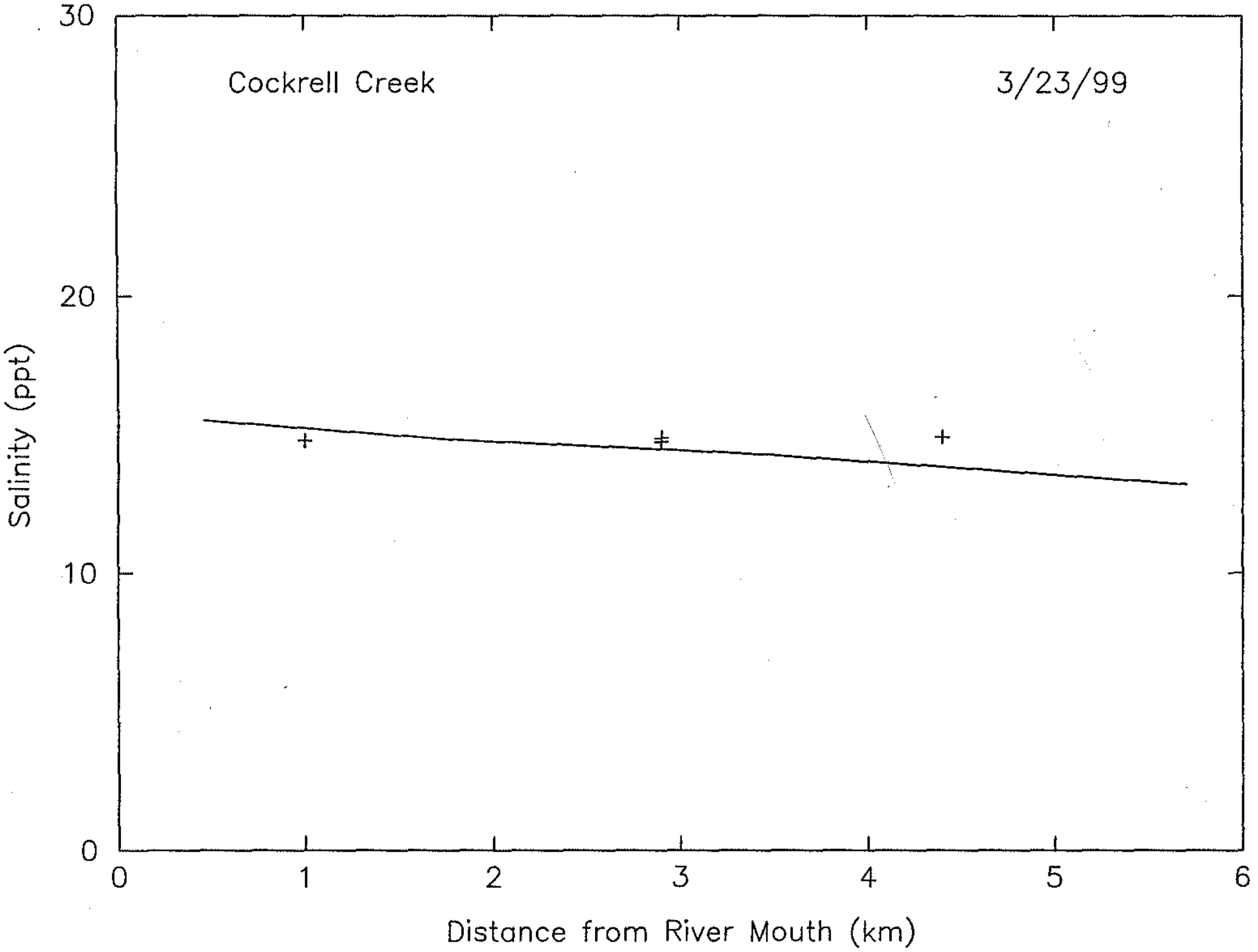

Cockrell Creek
3/23/99
Salinity (ppt)
30
20
10
0
0
1
2
3
4
5
6
Distance from River Mouth (km)

Fig. 3-3 (d)

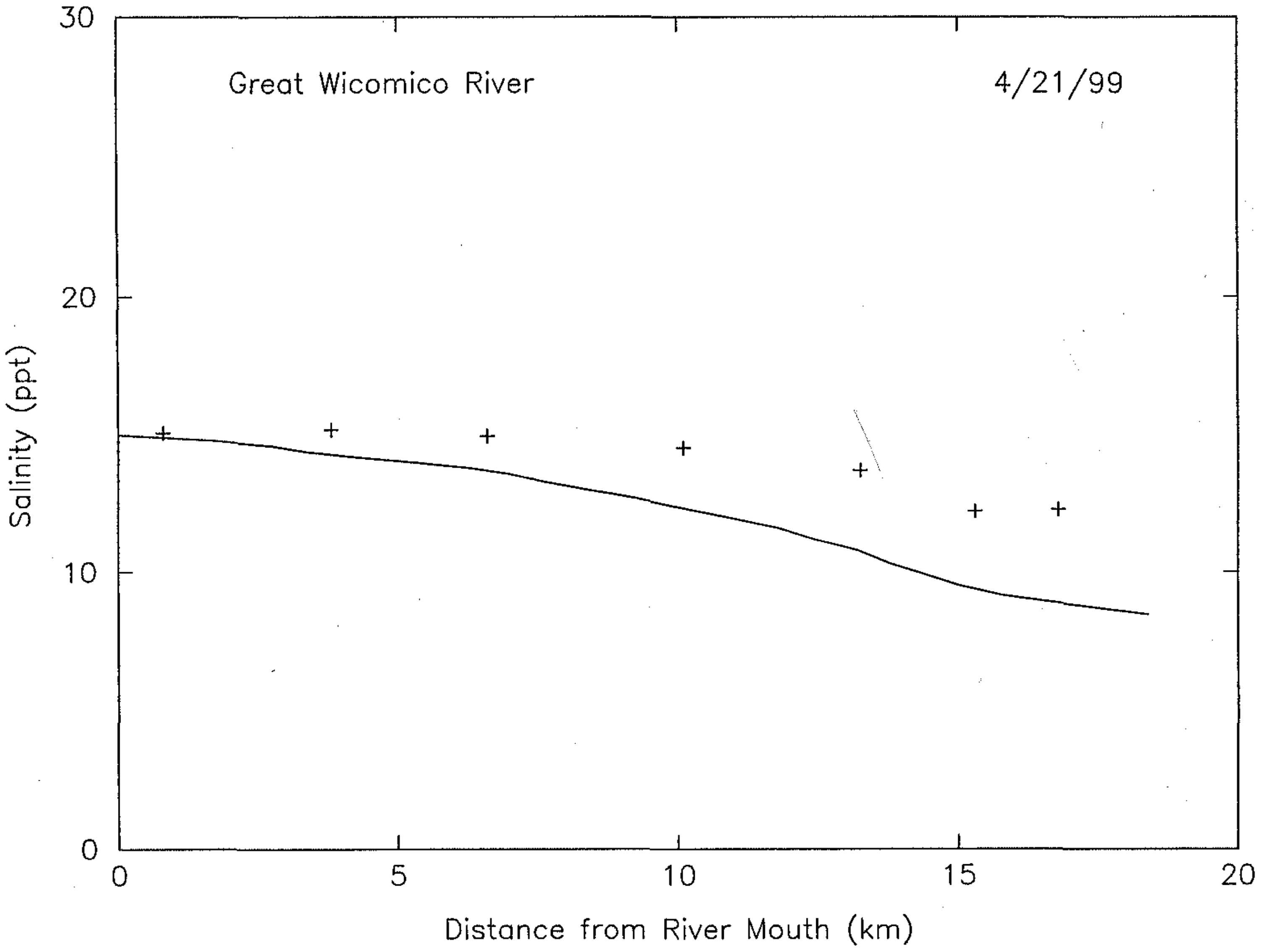

Great Wicomico River
4/21/99
Salinity (ppt)
30
20
10
0
0
5
10
15
20
Distance from River Mouth (km)

Fig. 3-3 (e)

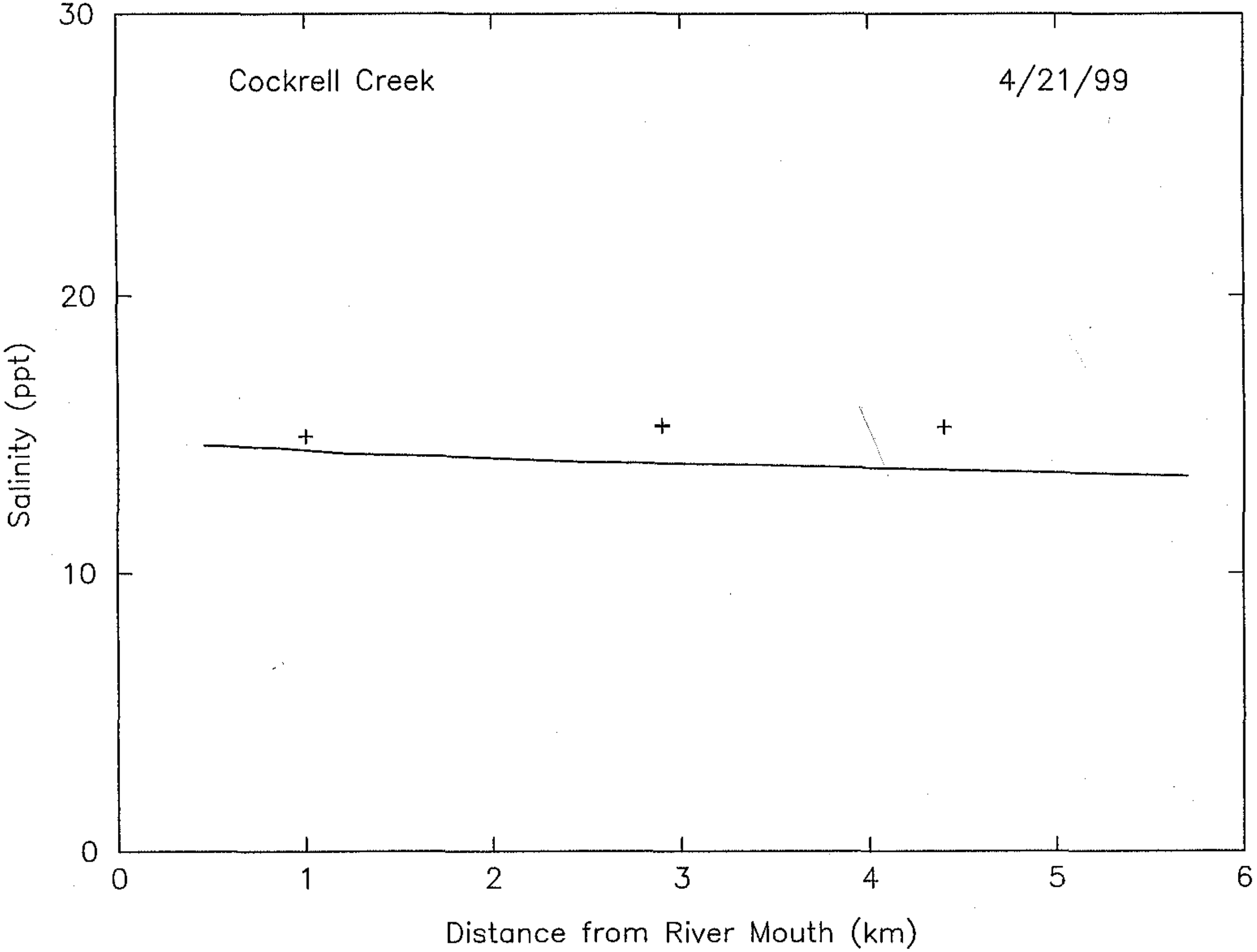

Cockrell Creek
4/21/99
Salinity (ppt)
30
20
10
0
0
1
2
3
4
5
6
Distance from River Mouth (km)

Fig. 3-3 (f)

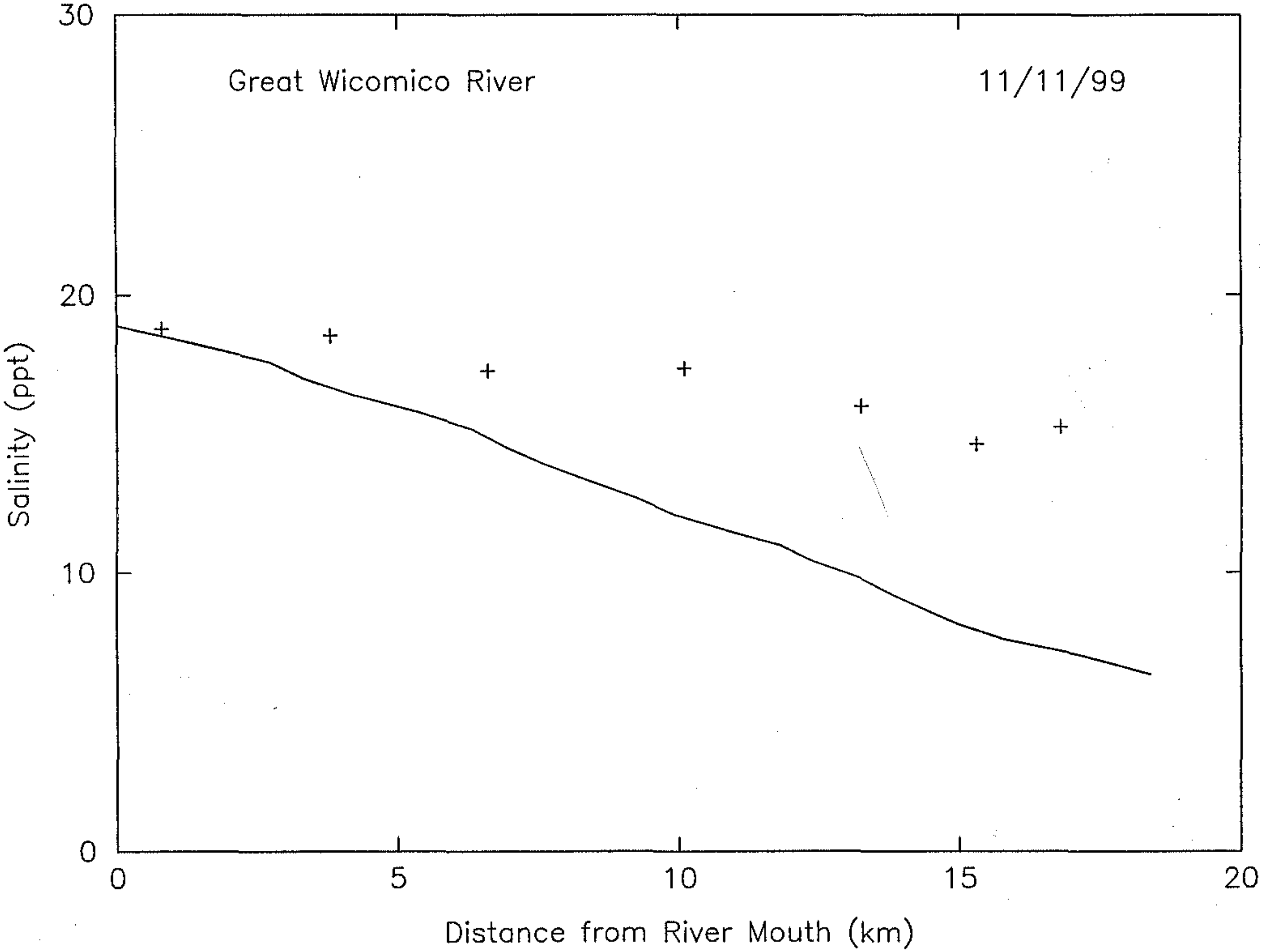

Great Wicomico River
11/11/99
Salinity (ppt)
Distance from River Mouth (km)
0
10
20
30
0
5
10
15
20

Fig. 3-3 (g)

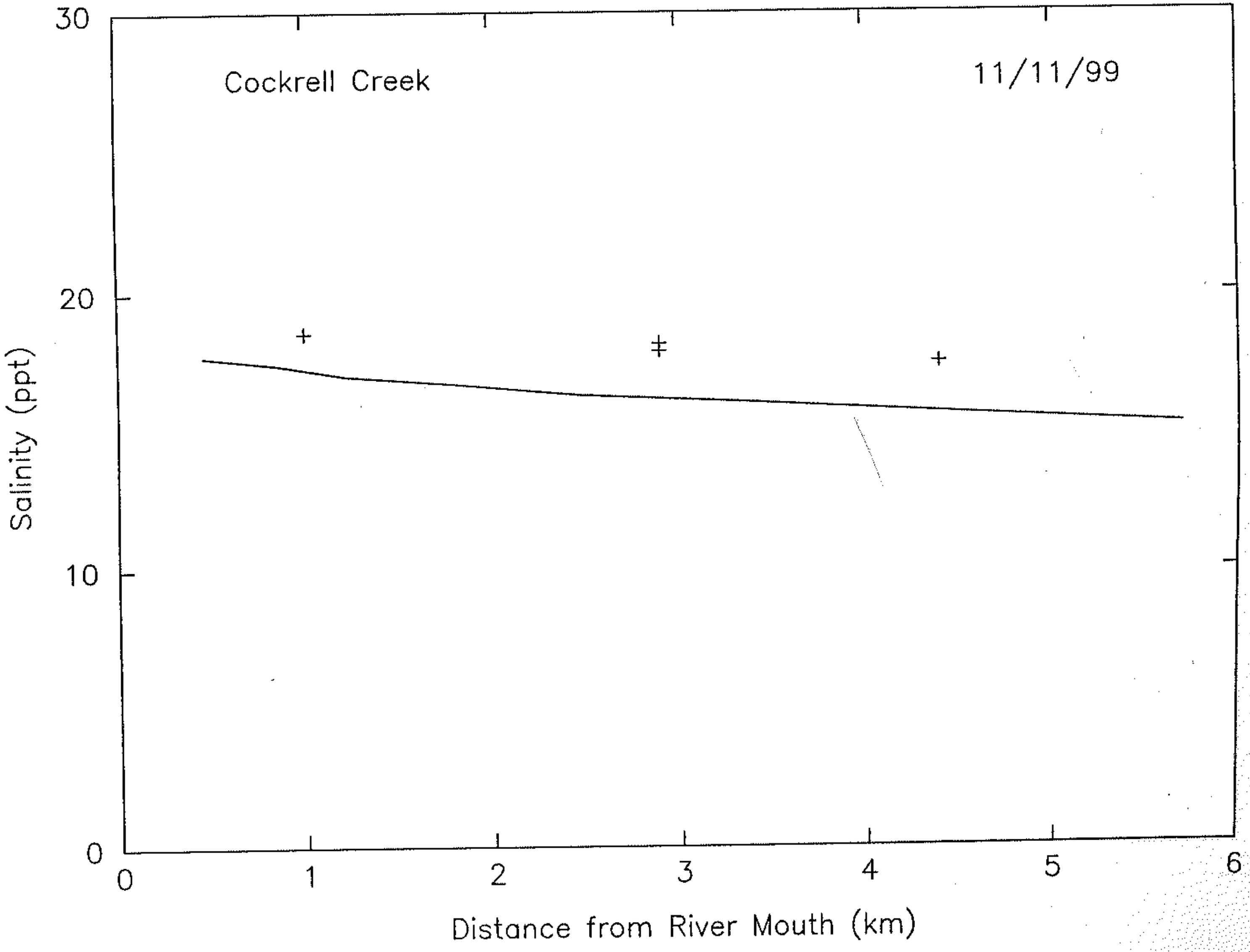

Cockrell Creek
11/11/99
Salinity (ppt)
30
20
10
0
0
1
2
3
4
5
6
Distance from River Mouth (km)

Fig. 3-3 (h)

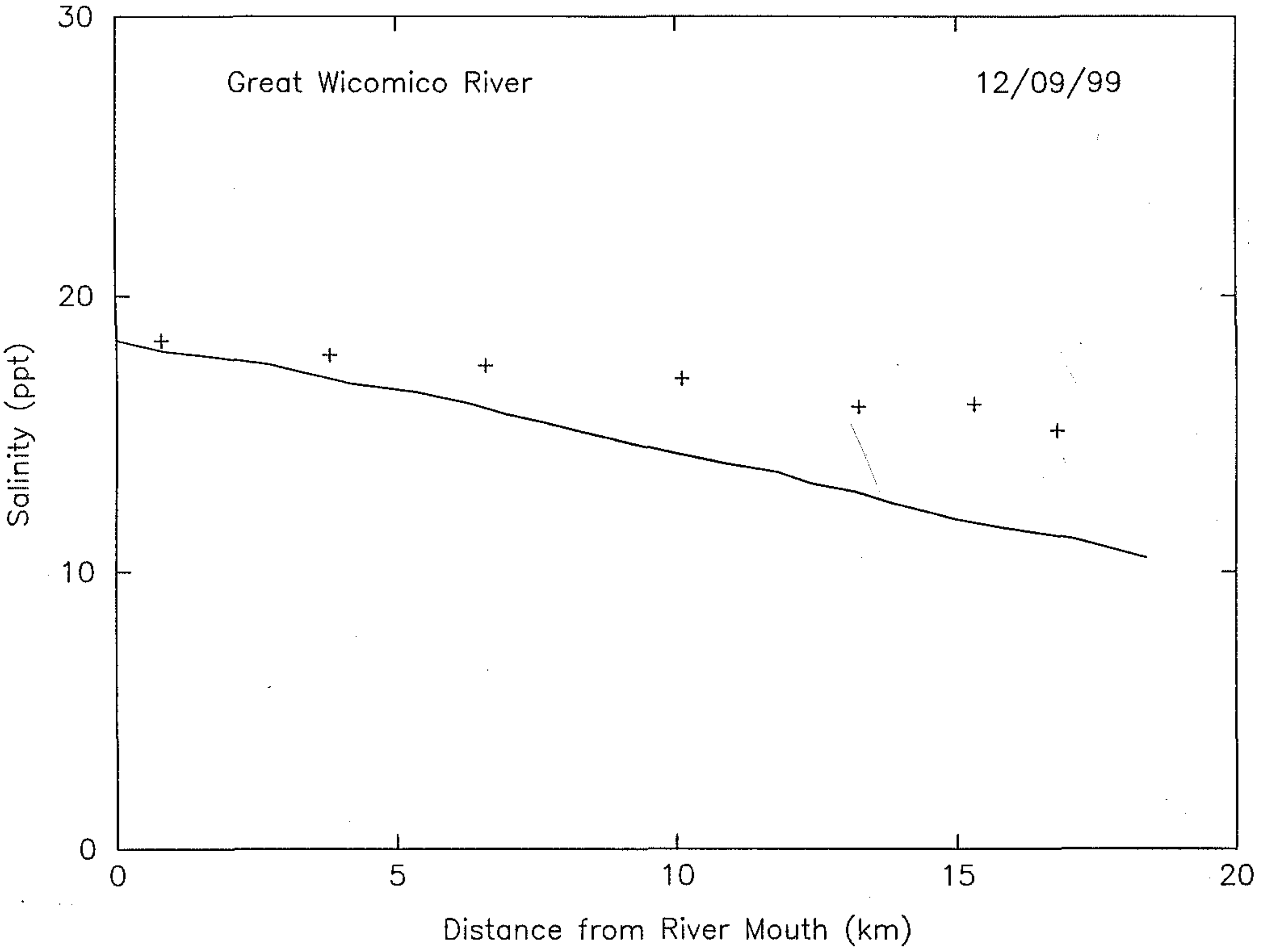

Great Wicomico River
12/09/99
Salinity (ppt)
30
20
10
0
0
5
10
15
20
Distance from River Mouth (km)

Fig. 3-3 (i)

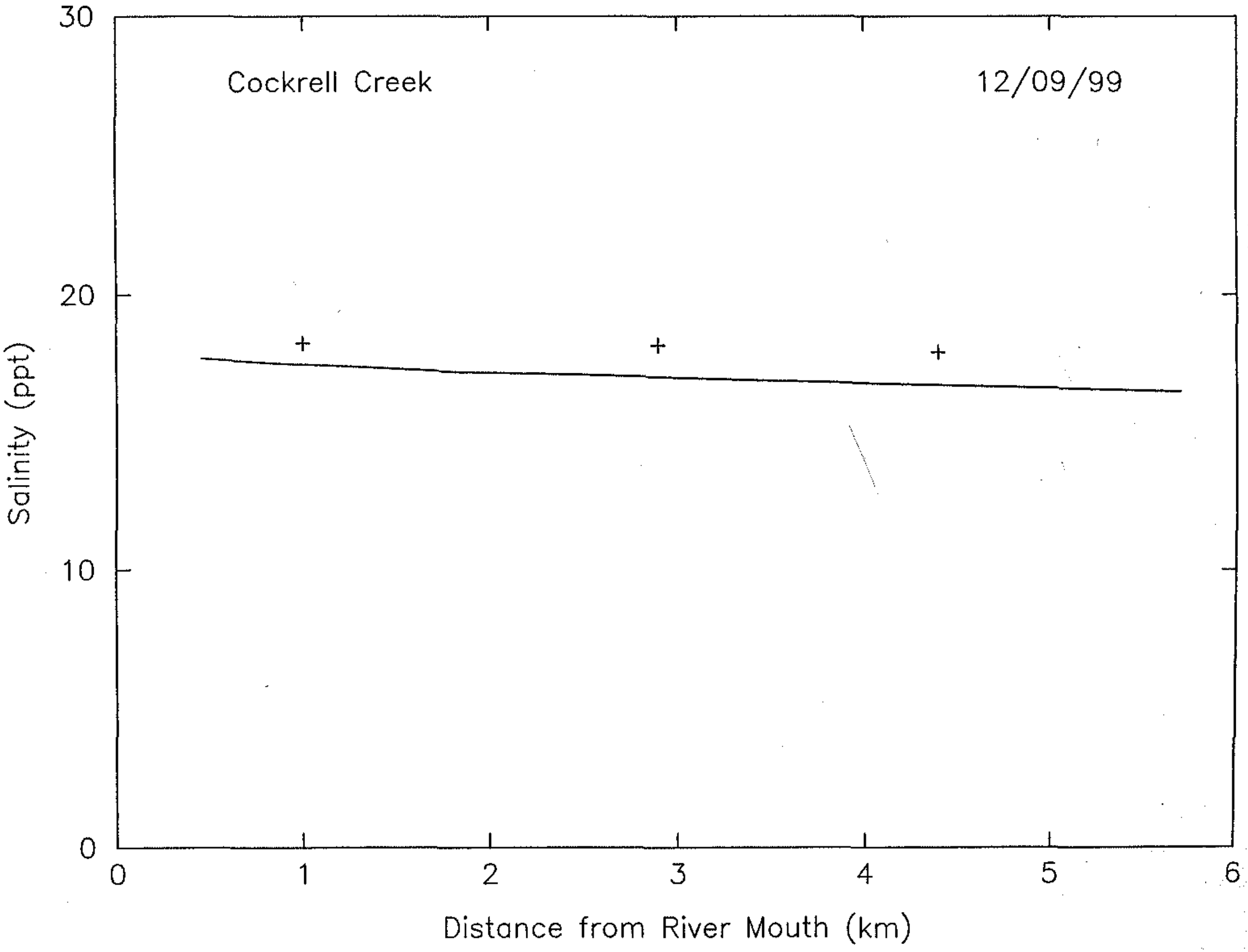

Cockrell Creek
12/09/99
Salinity (ppt)
0
10
20
30
Distance from River Mouth (km)
0
1
2
3
4
5
6

Fig. 3-3 (j)

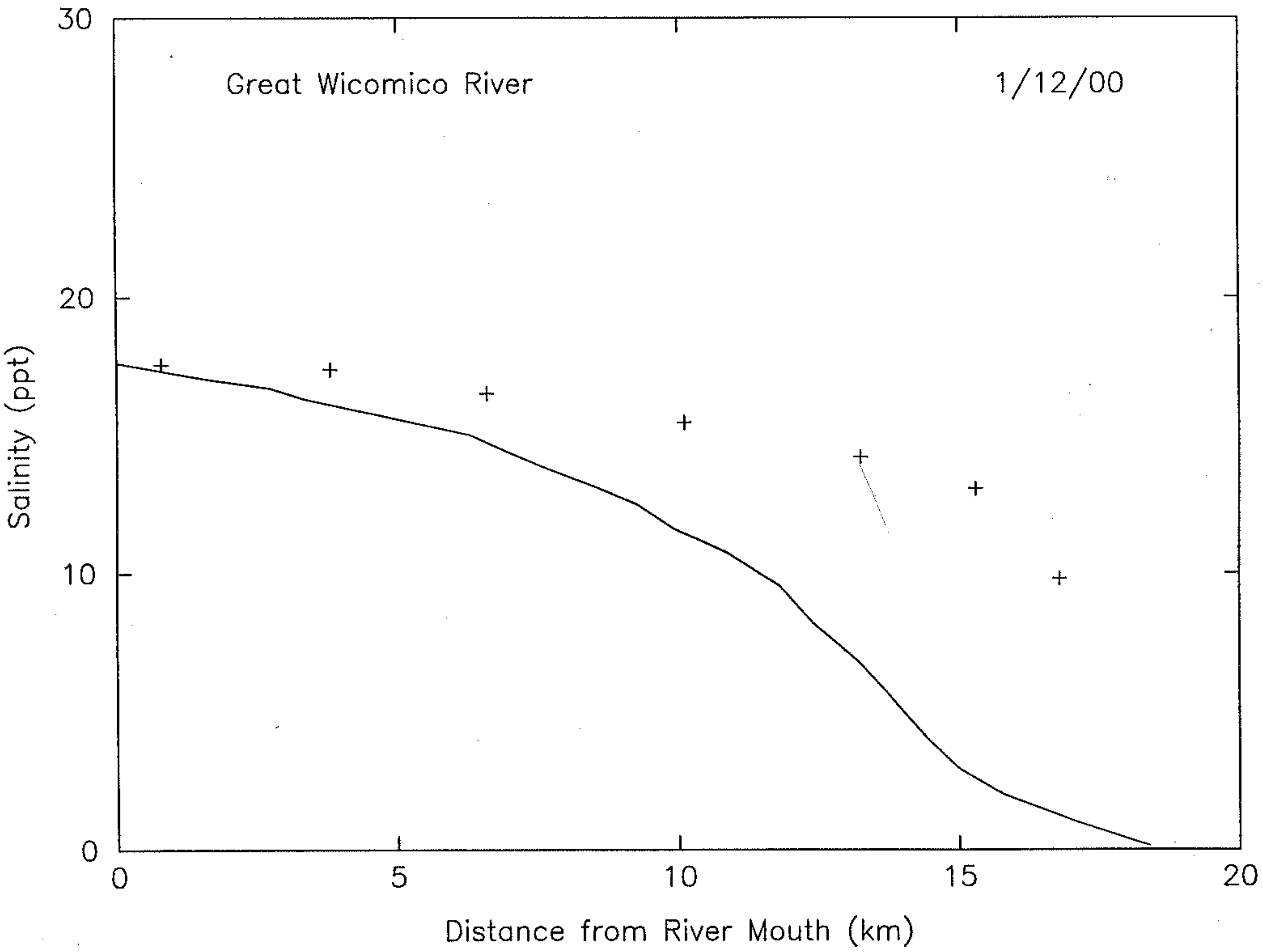

Great Wicomico River
1/12/00
Salinity (ppt)
30
20
10
0
0
5
10
15
20
Distance from River Mouth (km)

Fig. 3-3 (k)

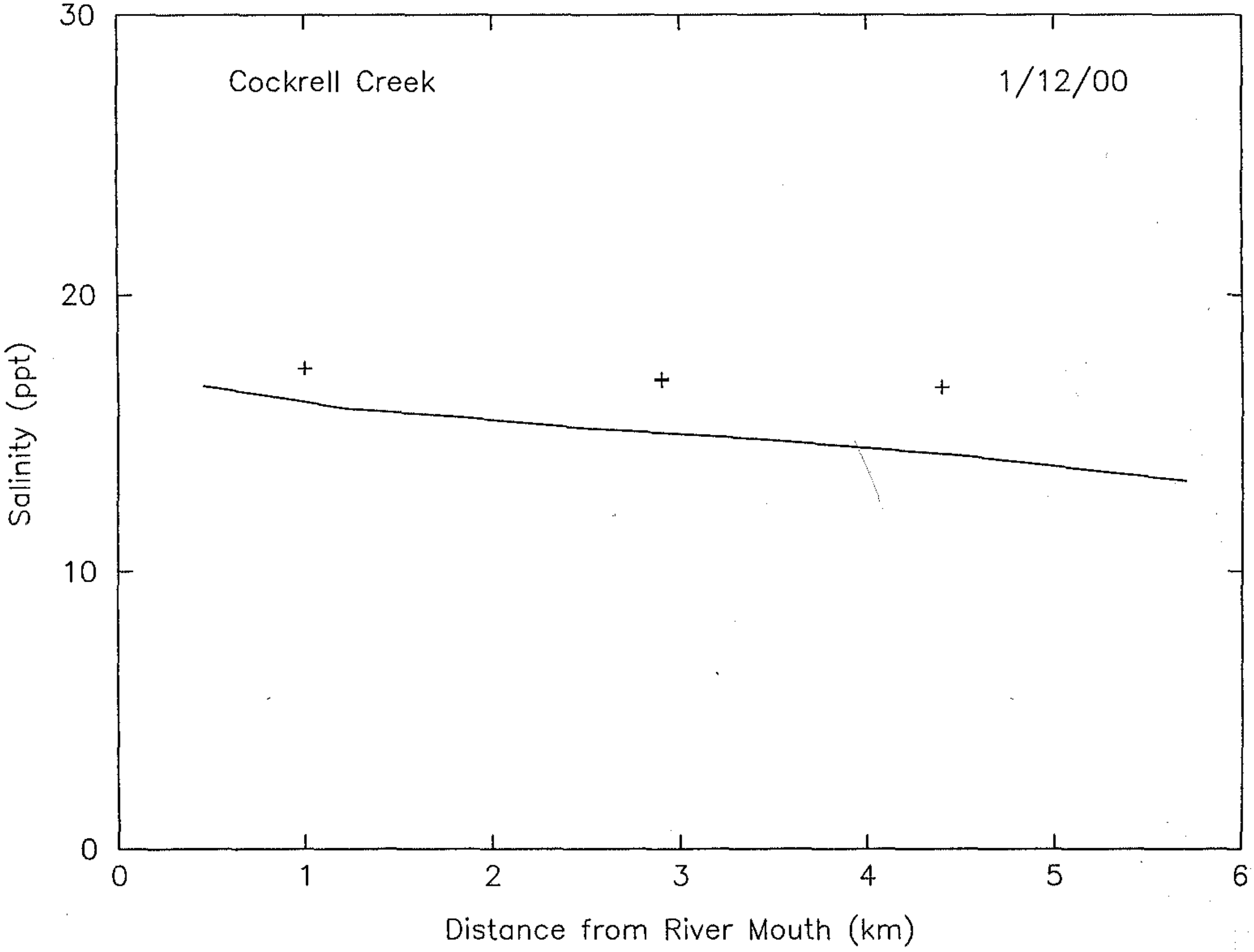

Cockrell Creek
1/12/00
30
20
10
0
Salinity (ppt)
0
1
2
3
4
5
6
Distance from River Mouth (km)

Fig. 3-3 (l)

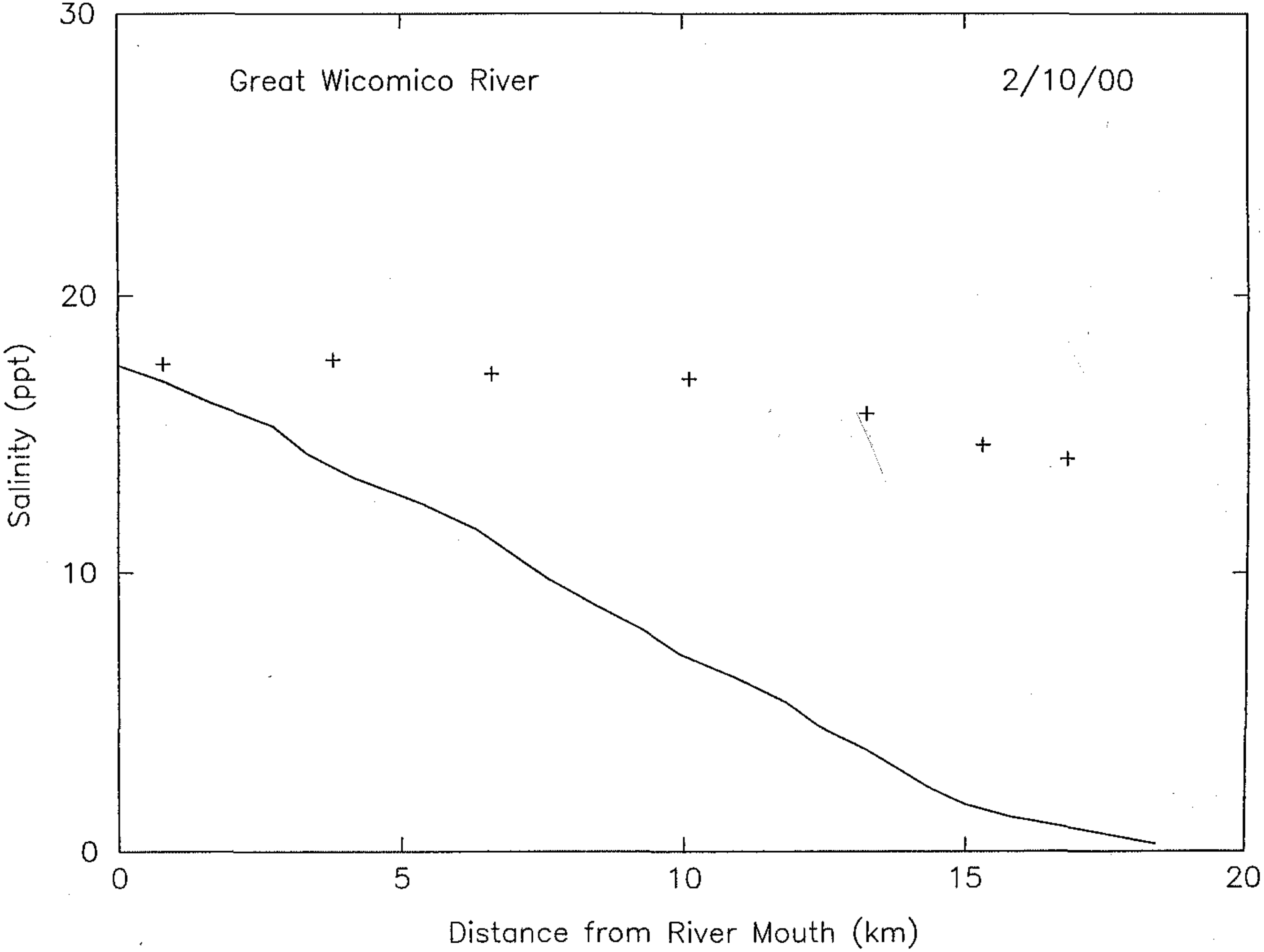

Great Wicomico River
2/10/00
30
20
10
0
Salinity (ppt)
0
5
10
15
20
Distance from River Mouth (km)

Fig. 3-3 (m)

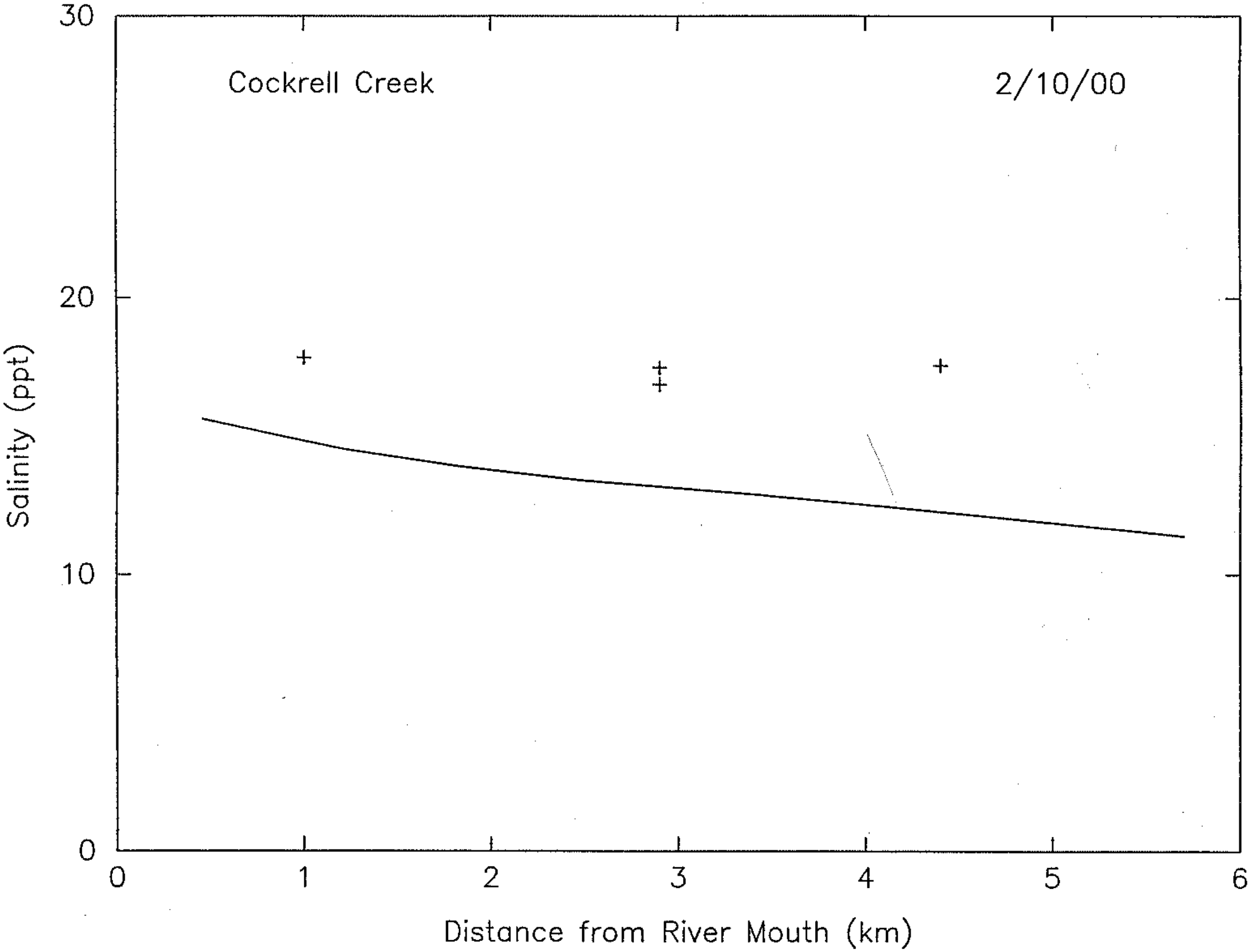

Cockrell Creek
2/10/00
Salinity (ppt)
30
20
10
0
0
1
2
3
4
5
6
Distance from River Mouth (km)

Fig. 3-3 (n)

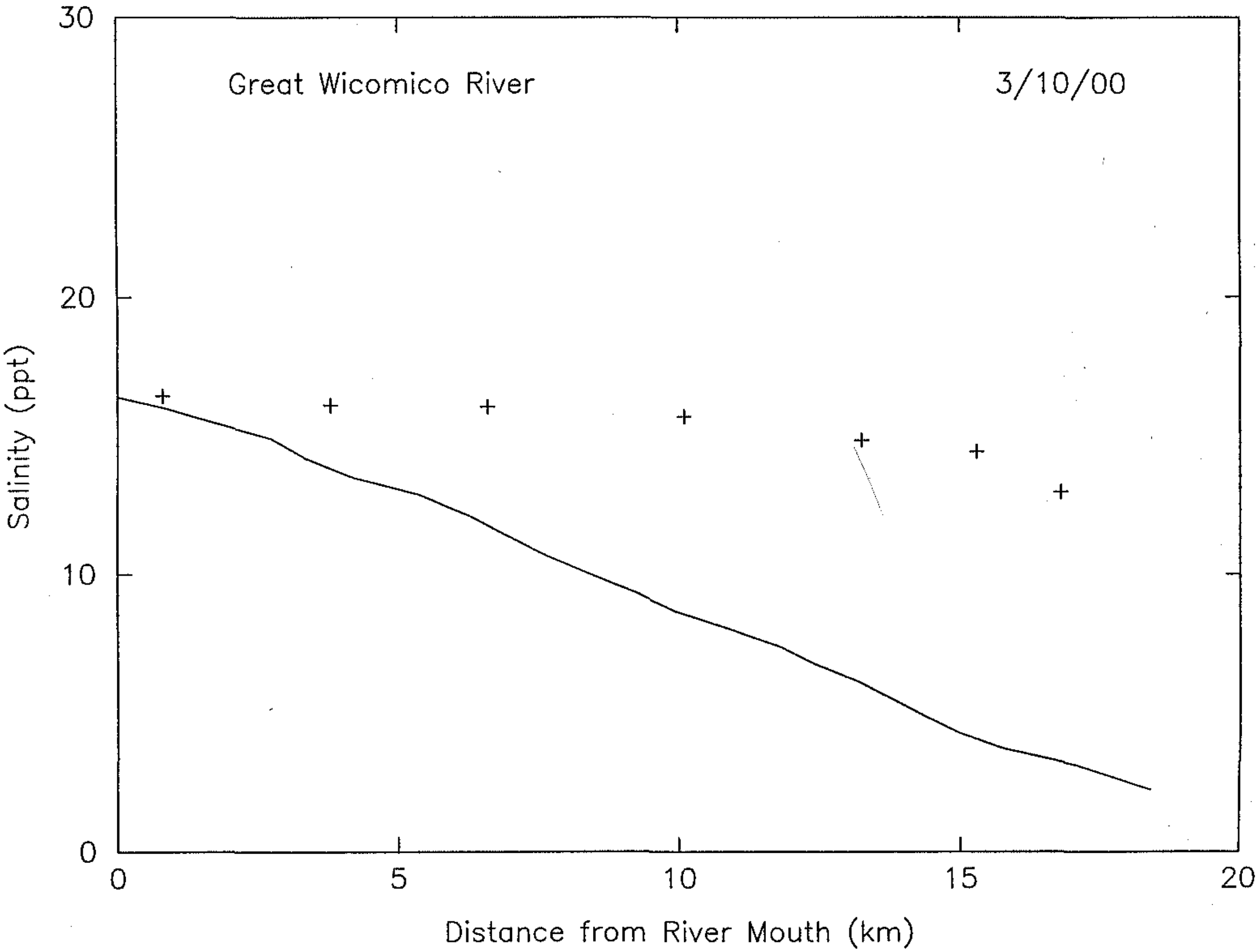

Great Wicomico River
3/10/00
Salinity (ppt)
30
20
10
0
0
5
10
15
20
Distance from River Mouth (km)

Fig. 3-3 (o)

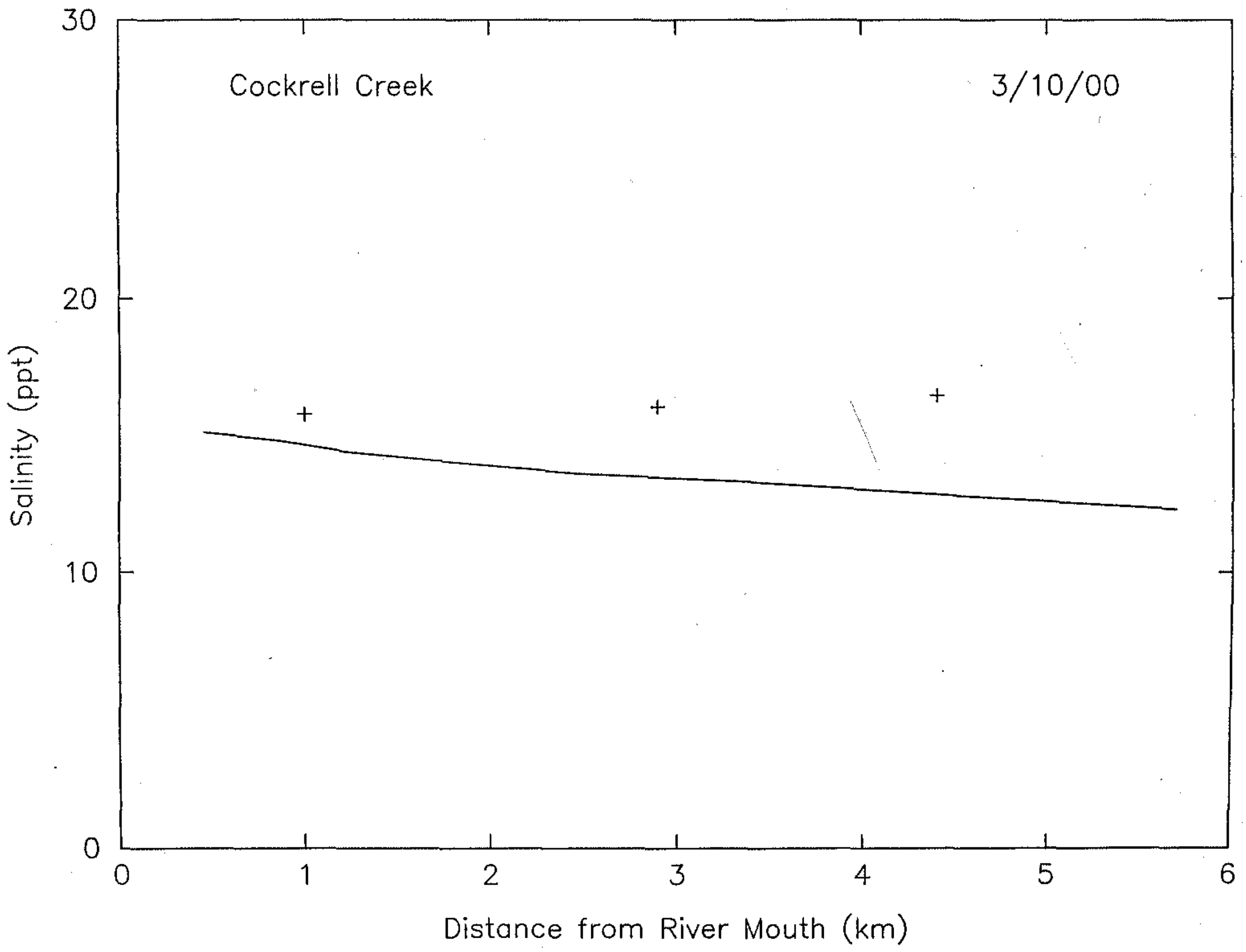

Cockrell Creek
3/10/00
Salinity (ppt)
30
20
10
0
Distance from River Mouth (km)
0
1
2
3
4
5
6

Fig. 3-3 (p)

IV. Summary and Conclusion

The watershed model BasinSim was applied to the Great Wicomico River basin of Virginia. The watershed was divided into 15 sub-basins and the model was applied to each. The model was calibrated with the only available stream flow data measured by USGS at the gauging station in the Bush Mill Stream during the period 1971-1985. Since the closest precipitation data during the same period is at Warsaw, Virginia, it was used for model input.The model was then used to generate stream flow, and nutrient and sediment loads for the period March 1998 to March 2000, using a precipitation record provided by a private citizen near Reedsville, VA. The overall average total nitrogen and total phosphorus concentrations calculated by the model compared satisfactorily with field measurements. However the model over predicted suspended sediment concentrations.

The watershed model BasinSim was coupled with the tidal prism water quality (TPWQM) to simulate the water quality conditions in the Great Wicomico River for the period February 1999 to March 2000. The model calculated salinity levels in the river are much lower than the observed data. No adjustment of model calibration parameter could rectify the discrepancy. A sensitivity run was conducted assuming that the groundwater portion of flow computed by BasinSim does not contribute to the freshwater input to the Great Wicomico River. Although the model predicted salinity agrees much better with field observation, there are still two unresolved problems. Firstly, BasinSim calculates monthly average stream flow and TPWQM operates in a time scale of tidal cycle. The coupled models can not be expected to simulate the day to day variation in salinity. Secondly, even considering the surface runoff alone, the freshwater input calculated by BasinSim still over dilutes the salinity in the river during the period of extreme heavy rainfall. It is not certain whether the location of precipitation measurement, skewed to the downriver end of watershed, contributes to this discrepancy. For further model calibration, it is recommended that at least a rain gauge be established at the upriver side of the watershed. Stream flow, as well as nutrient and sediment concentrations, should be continuously monitored during runoff events. Furthermore, an investigation of the groundwater contribution should be conducted.

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