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A water quality study of the eastern branch of the Lynnhaven Bay, Virginia

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A WATER QUALITY STUDY OF THE EASTERN BRANCH OF THE LYNNHAVEN BAY, VIRGINIA

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A Report to the

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I. Introduction

To alleviate the flooding in the drainage basin of the Lynnhaven River at Virginia Beach, Virginia, the U. S. Army Corps of Engineers has proposed to improve the waterways along the headwater of the river (House Document, 1976). The improvements include the widening and deepening of the existing canal, and the dredging of a new canal. As a result of the proposed project and the present rate of increase in area development, the freshwater runoff from the drainage basin and the tidal prism in the system are expected to increase. Since nonpoint sources are the only source of pollutants to the Eastern Branch of the Bay, the increase in freshwater runoff will have accompanying increase in pollutant loads of the same relative magnitude. The primary objective of this study is to assess the changes in water quality conditions as the results of the increases in freshwater discharge and in the tidal prism.

This study consists of two parts. The field survey includes two slack water runs and a dye release experiment. The model study consists of model validation and projection of water quality changes.

II. Field Survey

Two slack water runs were conducted on June 20 and August 13, 1979. The surveys were made at slack water before ebb following the sampling stations from the Lynnhaven

Inlet and along the Eastern Branch of the Lynnhaven Bay up to the Virginia Beach Boulevard bridge (Figure 1). Temperature, salinity, dissolved oxygen, TKN, five-day biochemical oxygen demand (nitrogen inhibited) and fecal coliforms were measured or sampled at all seven stations. Additional samples were taken at stations 2, 4 and 6 for nitrogen-inhibited ultimate BOD. The results of these field surveys are presented in Table 1.

A dye release experiment was conducted from August 6 through August 20, 1979. A total of 25 pounds of Rhodamine WT dye in solution was released at the tip of West Point (Figure 1). The dye was released into the river at a constant rate from 0327 to 0730 during the flood tide. Concentration distributions were measured along the axis of the Bay at slack waters before ebb subsequent to the release. Dye concentration was measured _in situ_ with a Turner Model 111 Fluorometer on a moving boat. The boat was also equipped with a small pump to draw the water from the Bay and circulate it continuously through the fluorometer, and with a Hewlett-Packard Model 680 Strip Chart Recorder for recording the data. The field data are shown with the results of model simulations in the next section.

Benthic oxygen demands were measured at stations 2, 4 and 6 in June 1979. The results are 1.2, 1.6 and 1.1 $gm/m^2/day$ at $20^{o}C$ for stations 2, 4 and 6 respectively.

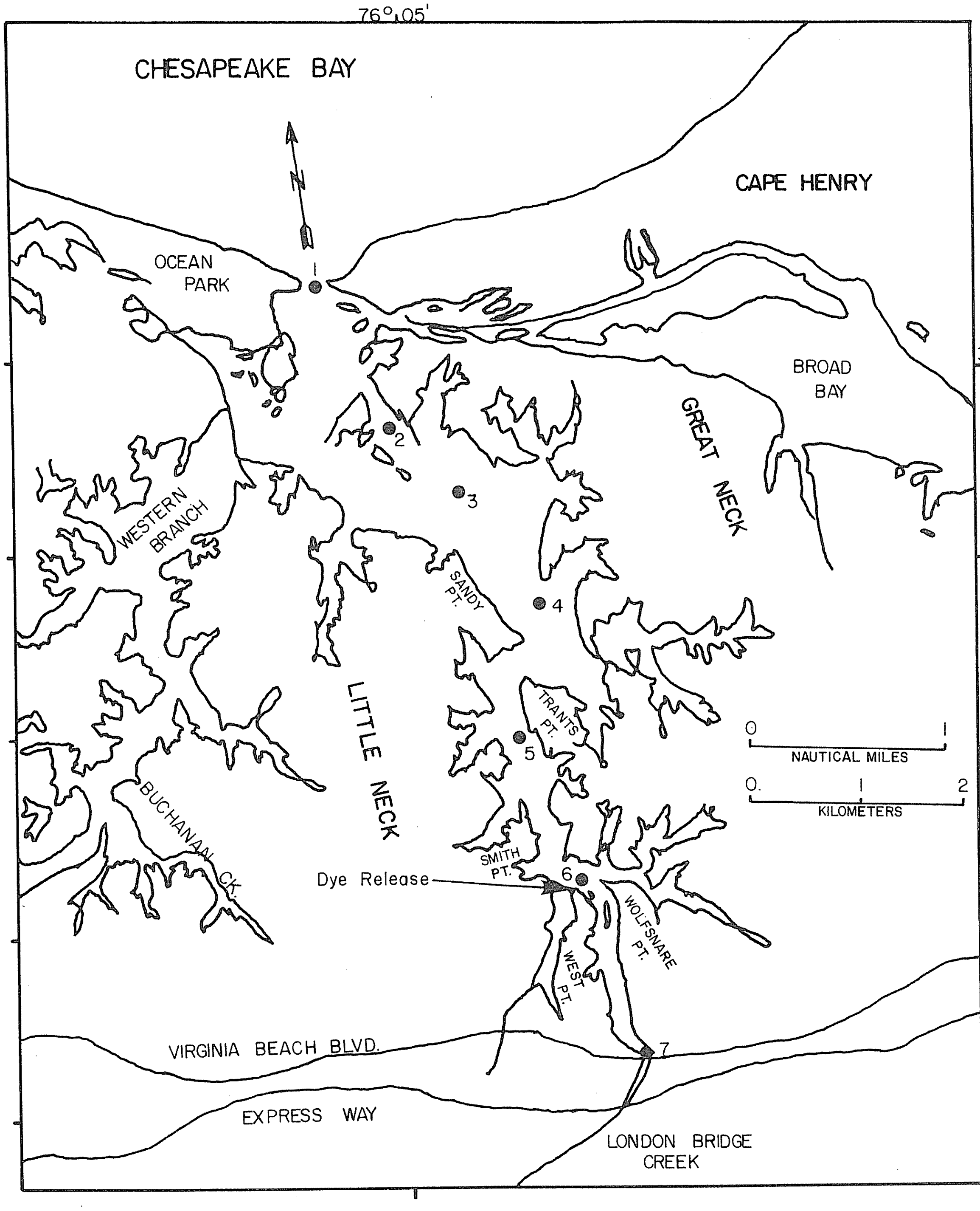

Figure 1. The Lynnhaven Bay showing the sampling stations.

Table 1. The Slack Water Run Results

(a) June 20, 1979

Station	Depth m	Temp. °C	Salinity ppt	D.O. mg/l	TKN mg/l	$CBOD_5$ mg/l	$CBOD_\infty$ mg/l	Fecal Coliform MPN/100 ml
1	1.0	20.5	18.7	7.2	0.43	1.10		4.5
	6.0	20.6	18.9	7.2	0.50	2.06		13
2	1.0	20.7	18.6	7.6	0.45	1.38	2.52	4.5
	3.0	20.7	18.7	7.2	0.48	1.31		2.0
3	2.0	20.9	18.5	7.3	0.45	1.20		ID
4	1.0	21.5	17.5	6.7	0.53	1.51	2.92	31
5	0.5	22.2	16.6	4.9	1.12	2.20		70
6	0.3	21.9	15.6	5.4	0.70	2.00	3.46	17
7	0.6	22.2	14.7	5.1	0.83	2.24		46

(b) August 13, 1979

Station	Depth m	Temp. °C	Salinity ppt	D.O. mg/l	TKN mg/l	$CBOD_5$ mg/l	$CBOD_\infty$ mg/l	Fecal Coliform MPN/100 ml
1	1.0	25.9	21.2	7.46	0.58	2.00		49
	3.0	25.9	21.2	7.34	0.59	3.40		110
2	1.0	25.5	21.2	8.00	0.55	2.02	2.60	49
	3.0	25.5	21.2	7.92	0.53	2.21		49
3	1.0	25.0	21.0	8.00	0.58	3.50		49
4	1.0	25.0	20.6	8.29	0.68	5.36*	4.82*	70
5	1.0	25.4	19.1	8.06	0.95	3.63		230
6	1.0	26.1	16.6	9.47	1.32	6.17*	5.56*	230
7	1.0	26.2	12.2	8.31	1.05	1.68		1700

*These figures are suspicious because $CBOD_5$ are greater than $CBOD_\infty$

III. Model Study

The model used in this study for water quality simulation was developed by VIMS for the Hampton Roads 208 Study (Ho, Kuo and Neilson, 1977). The model is a tidal prism model which accounts for the flushing by tide and freshwater runoff. Because of the shallowness of the Bay, the flushing by density circulation is negligible. The temperature and salinity data in Table 1 support this assumption.

For the purpose of model formulation, the Lynnhaven Bay and the Eastern Branch are considered as the main stem, and the Western Branch is treated as a tributary. Figure 2 shows the model segments of the Bay. Both the main stem and the Western Branch are divided into seven segments. In addition, there are four small creeks connecting to the main stem, each of them is treated as a single-segment tributary.

A. Model Calibration and Validation

The model was first calibrated with respect to the salinity distribution. The model was run to simulate the salt intrusion from 20 June to 13 August 1979. The field data of 20 June were input to the model as initial condition and the model parameters, returning ratio, was adjusted until the predicted salinity distribution agrees with field observation. The comparisons between field observation and model results are shown in Figures 3 and 4.

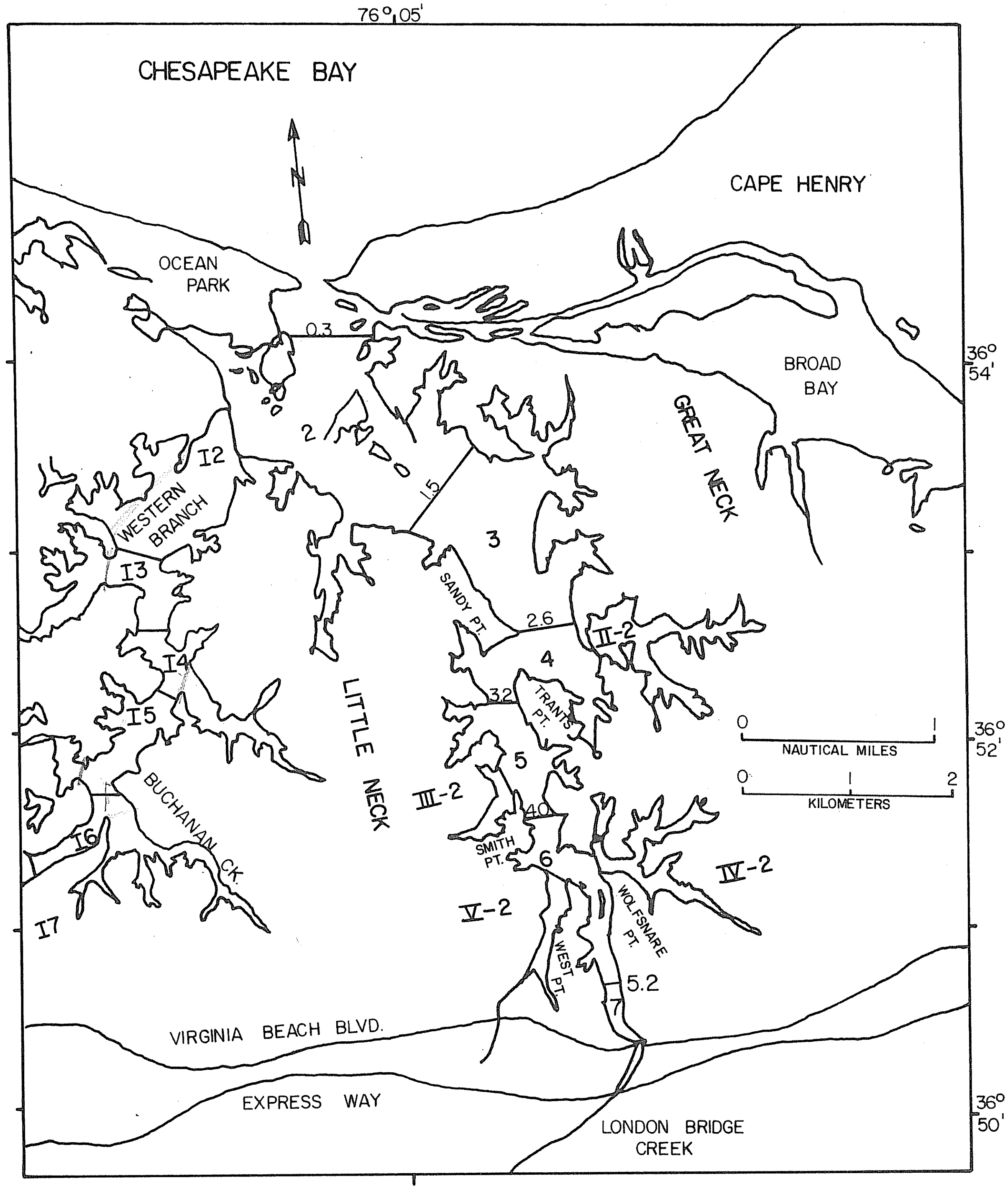

Figure 2. The Lynnhaven Bay showing the model segments.

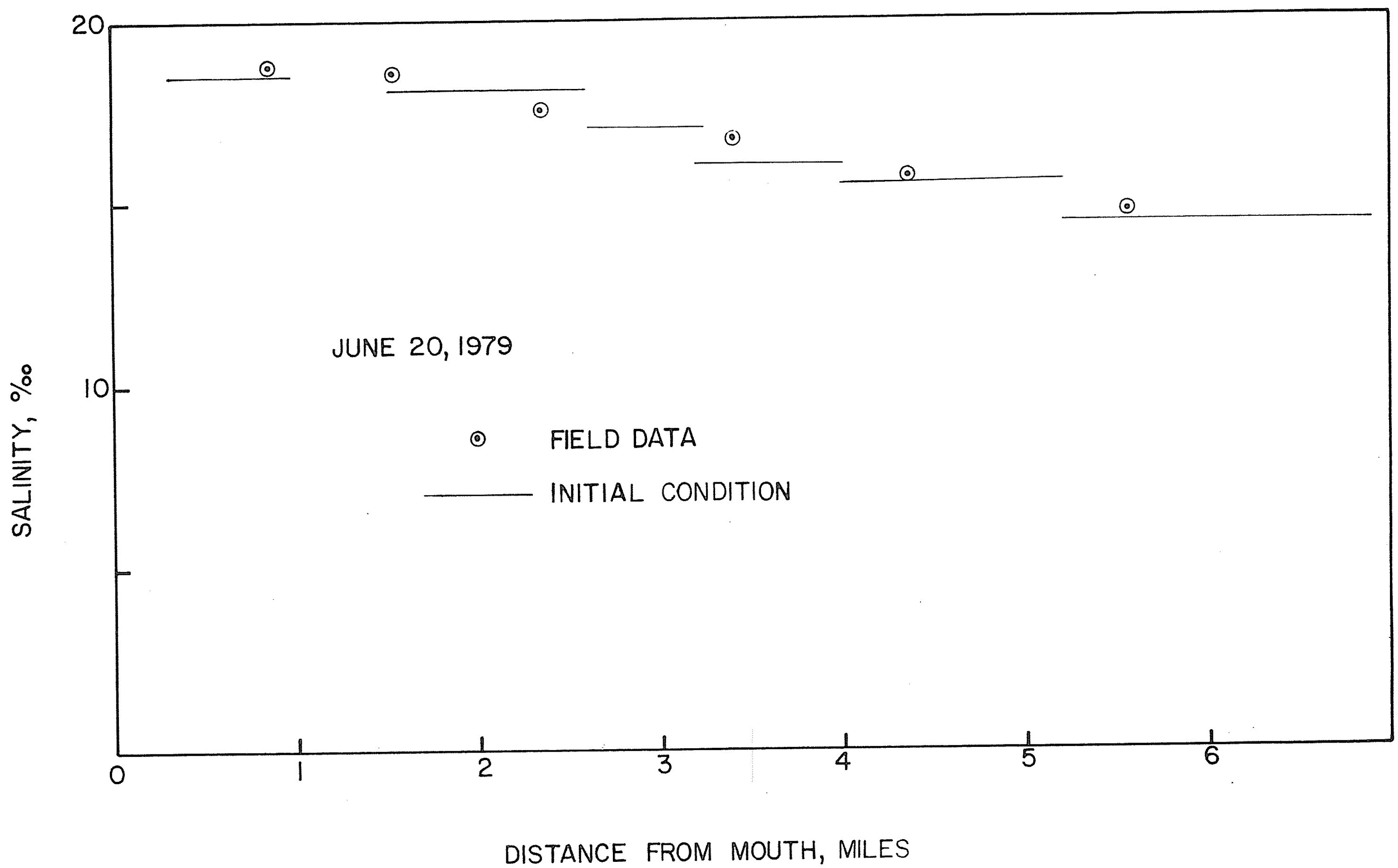

Figure 3. Salinity distribution on June 20, 1979.

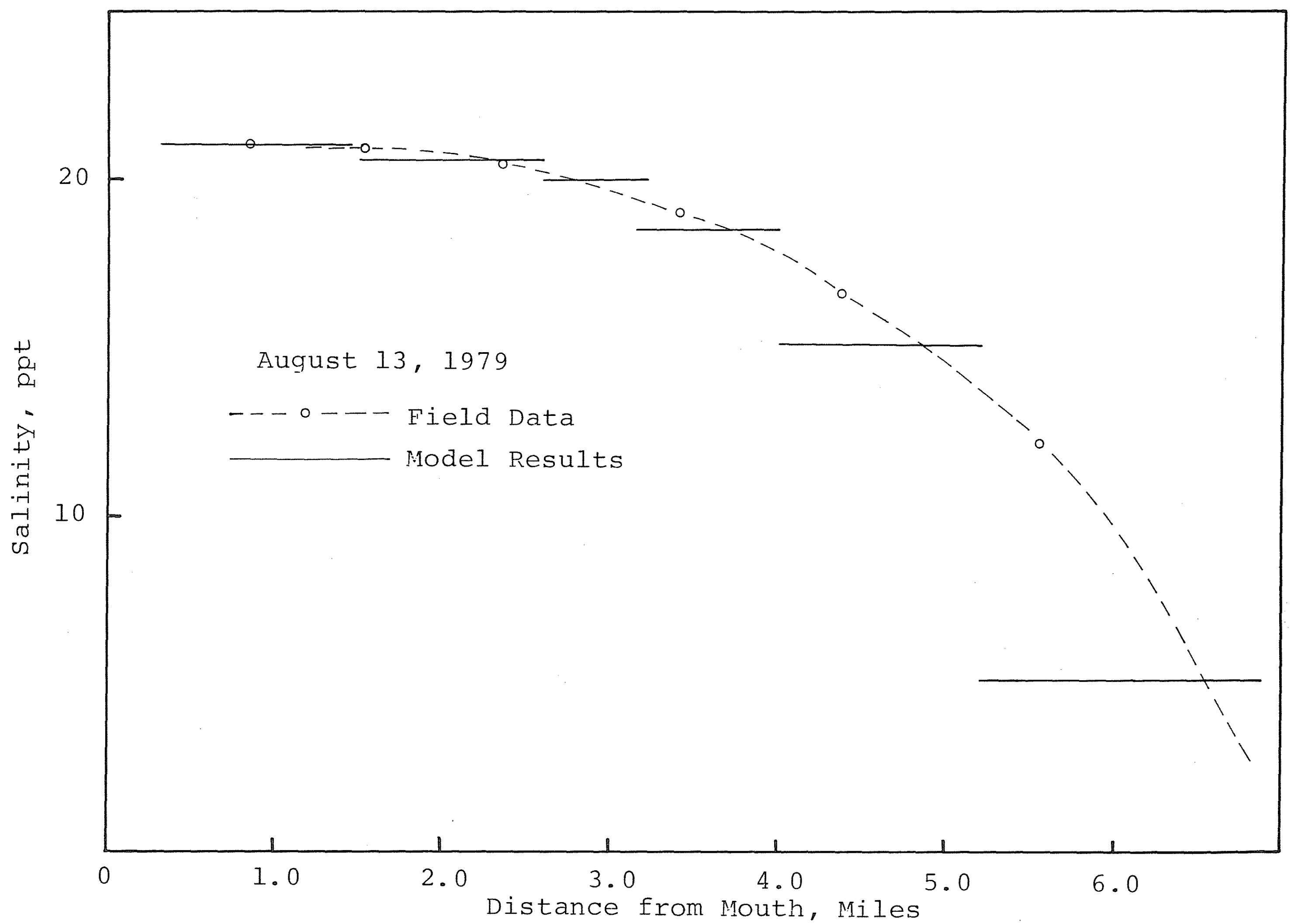

Figure 4. Salinity distribution on August 13, 1979.

The flushing mechanism of the model was validated with the data of dye-release experiment. One and a half tidal cycles were allowed for the initial phase of mixing after dye release. The concentration distribution of August 7 was input into the model as initial condition. The model was then run to simulate the flushing of dye. The comparisons between field data and model results are shown in Figures 5, 6 and 7. For both salt intrusion and dye flushing simulation runs, the freshwater input to the system was generated with a nonpoint source model STORM (developed for the Corps of Engineers, U. S. Army). The model generates the quantity and quality of daily runoff from the rainfall data. This non-point source information was also used for the validation of the water quality portion of the tidal prism model.

The model was run to simulate the water quality condition of the Bay from 1 June to 20 June, 1979. The STORM model was run first to generate the nonpoint source of pollutant and freshwater runoff during this 20 day period. The output of STORM model was edited and used as input data for the tidal prism model. The model coefficients of the water quality model were kept at the same values as those developed previously except the coliform die-off coefficient. The coliform die-off coefficient was reduced to 0.4/day in order to obtain a result matching the field data of 20 June, 1979. The model results are compared with field data in Figures 8 to 11.

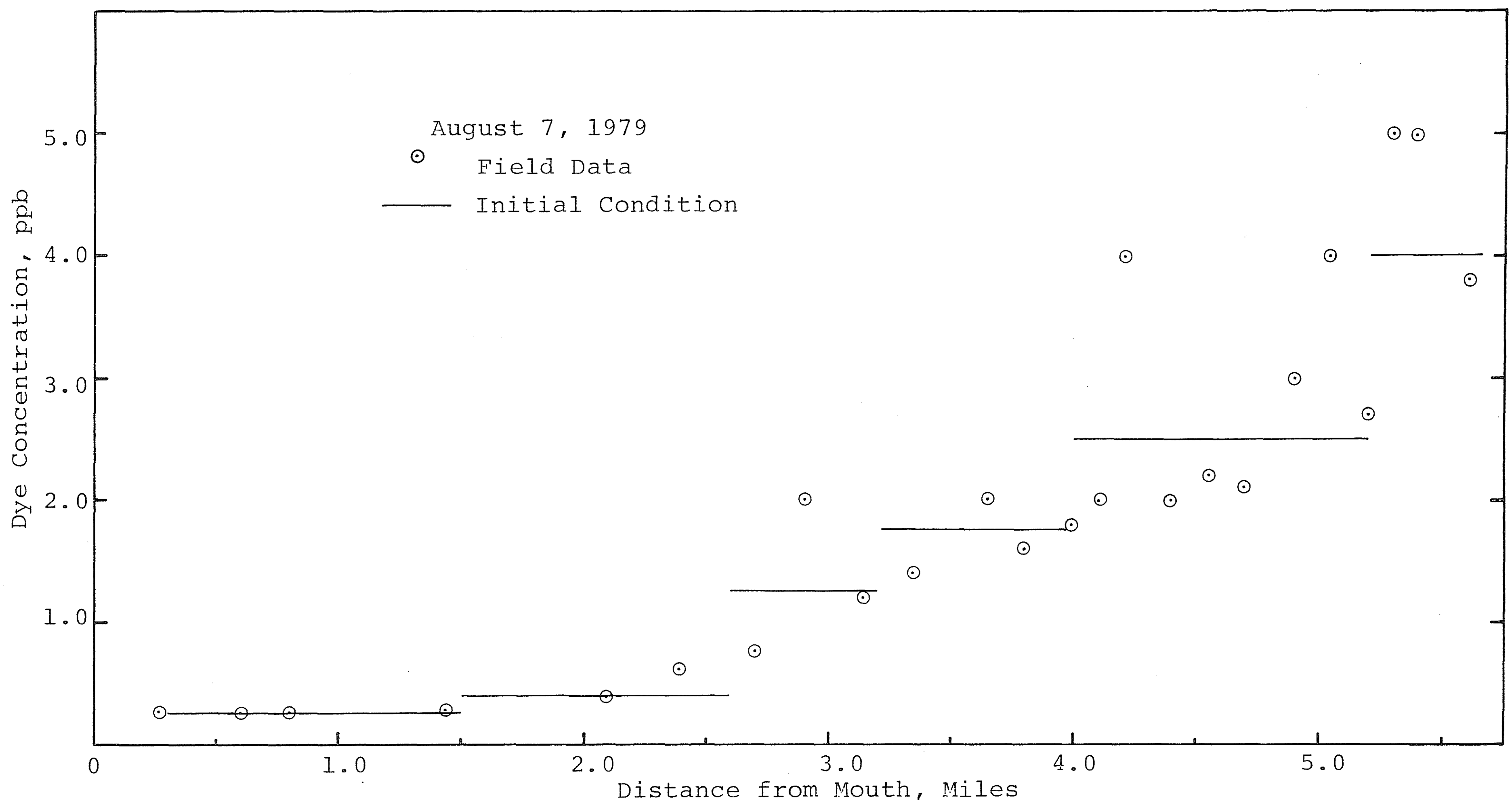

Figure 5. Dye distribution on August 7, 1979.

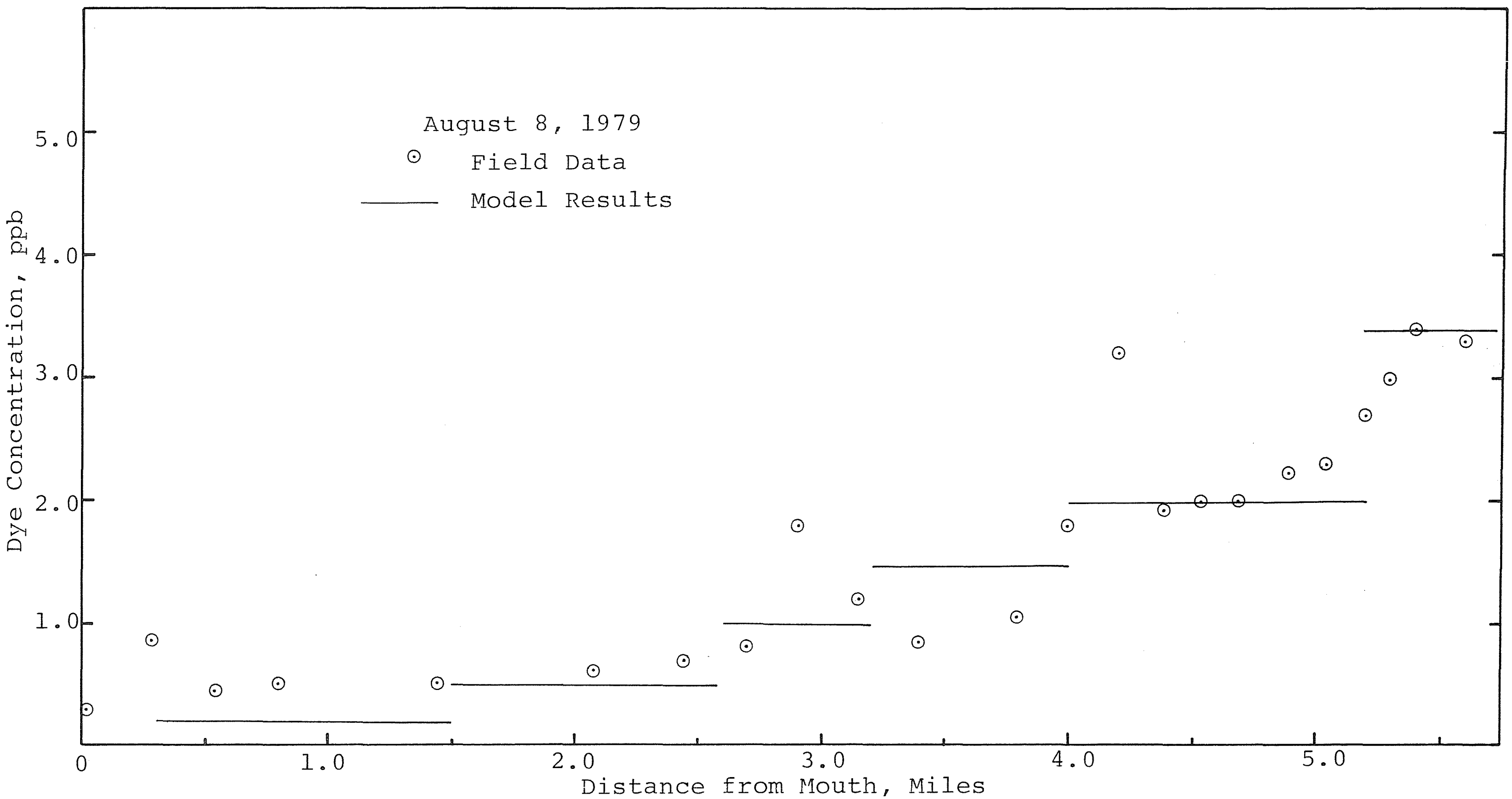

Figure 6. Dye distribution on August 8, 1979.

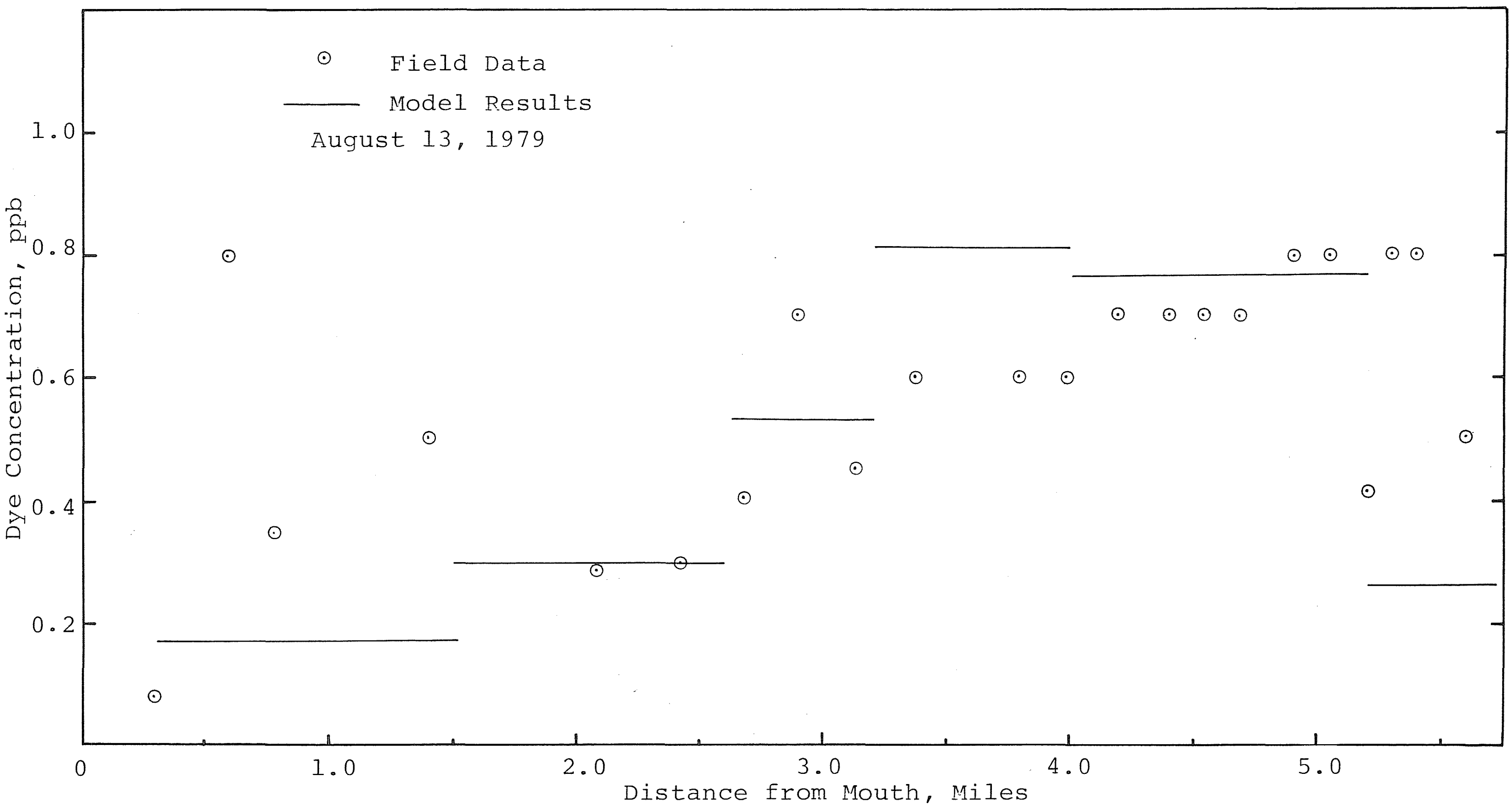

Figure 7. Dye distribution on August 13, 1979.

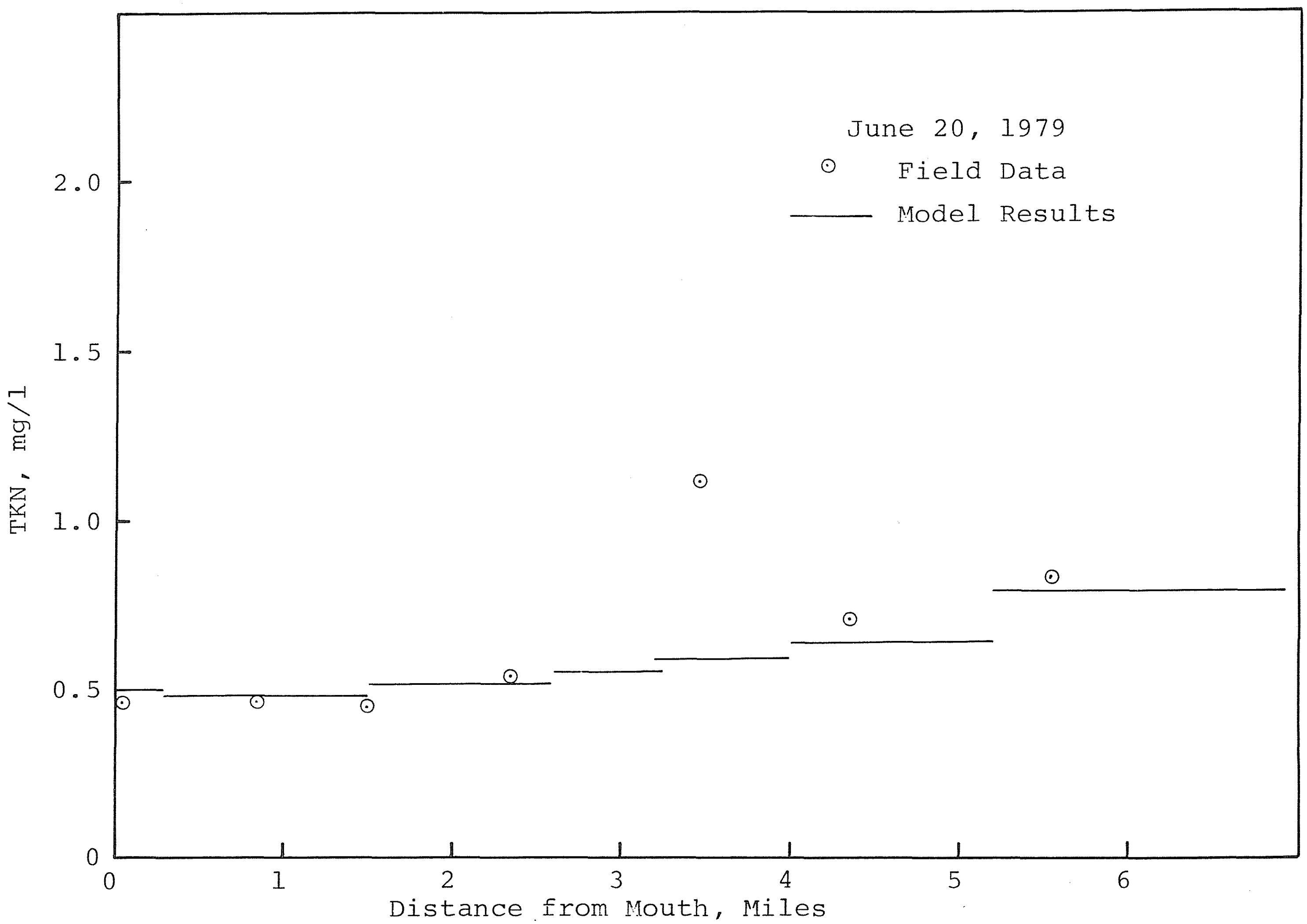

Figure 8. TKN distribution on June 20, 1979.

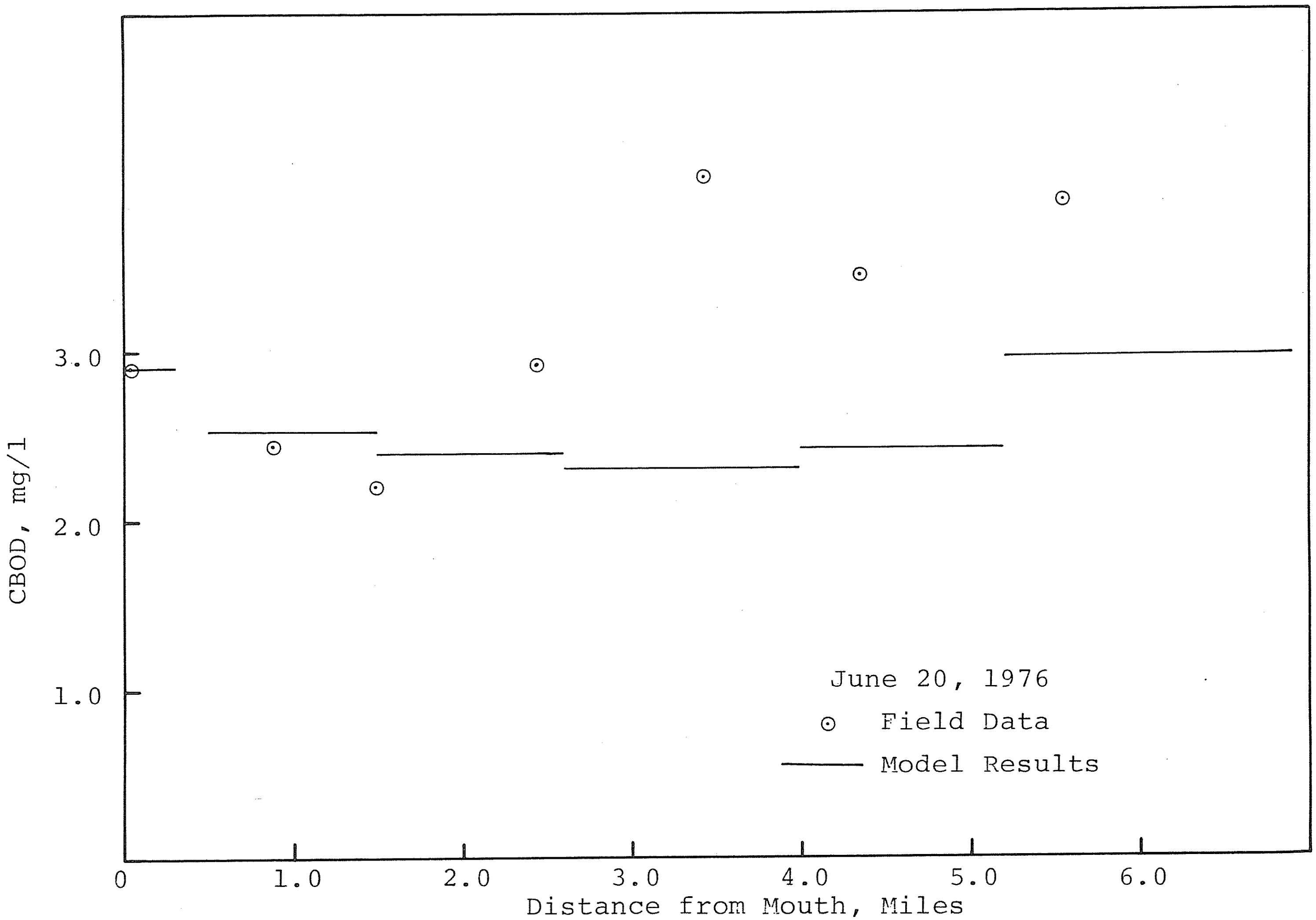

Figure 9. CBOD distribution on June 20, 1979.

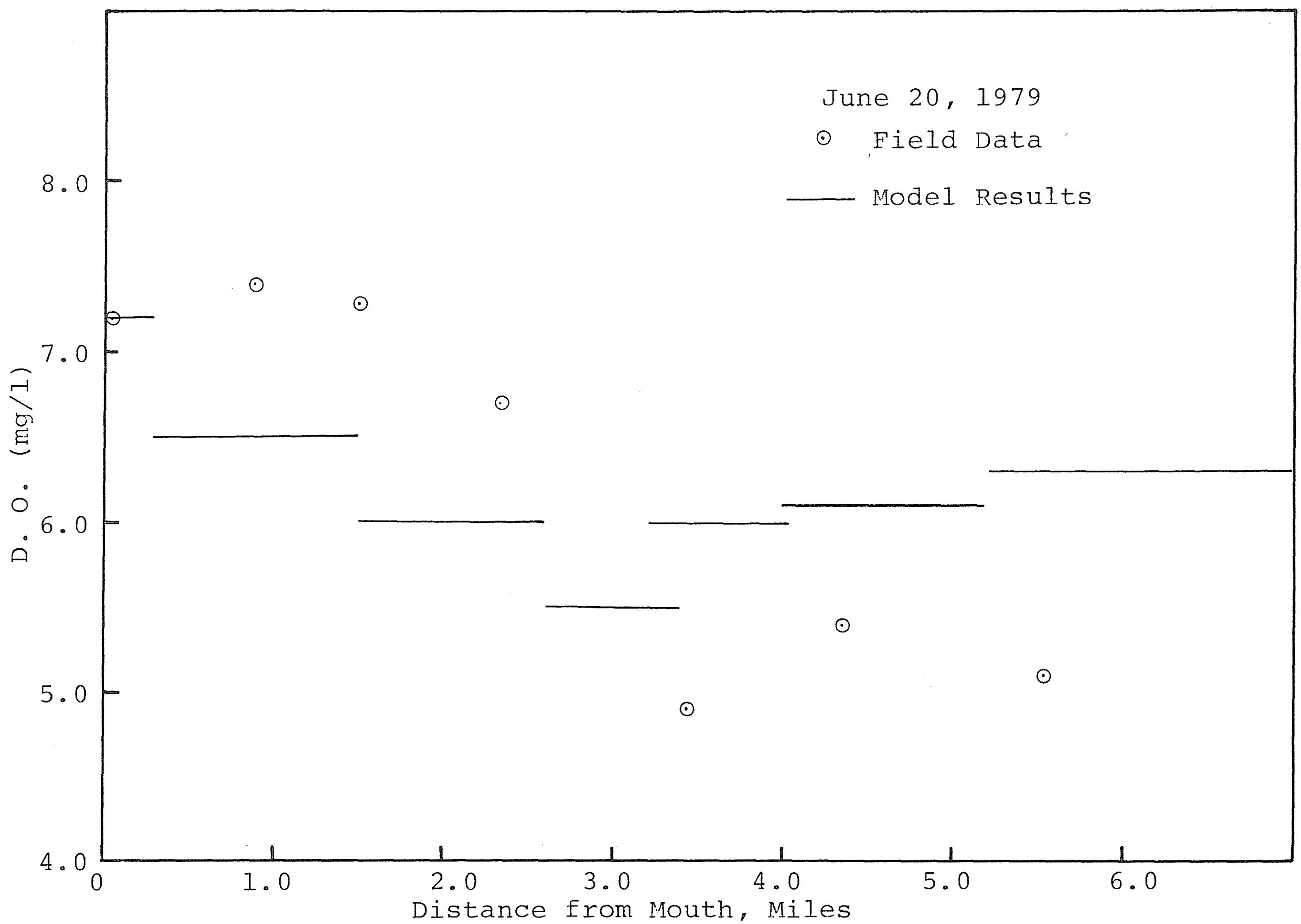

Figure 10. DO distribution on June 20, 1979.

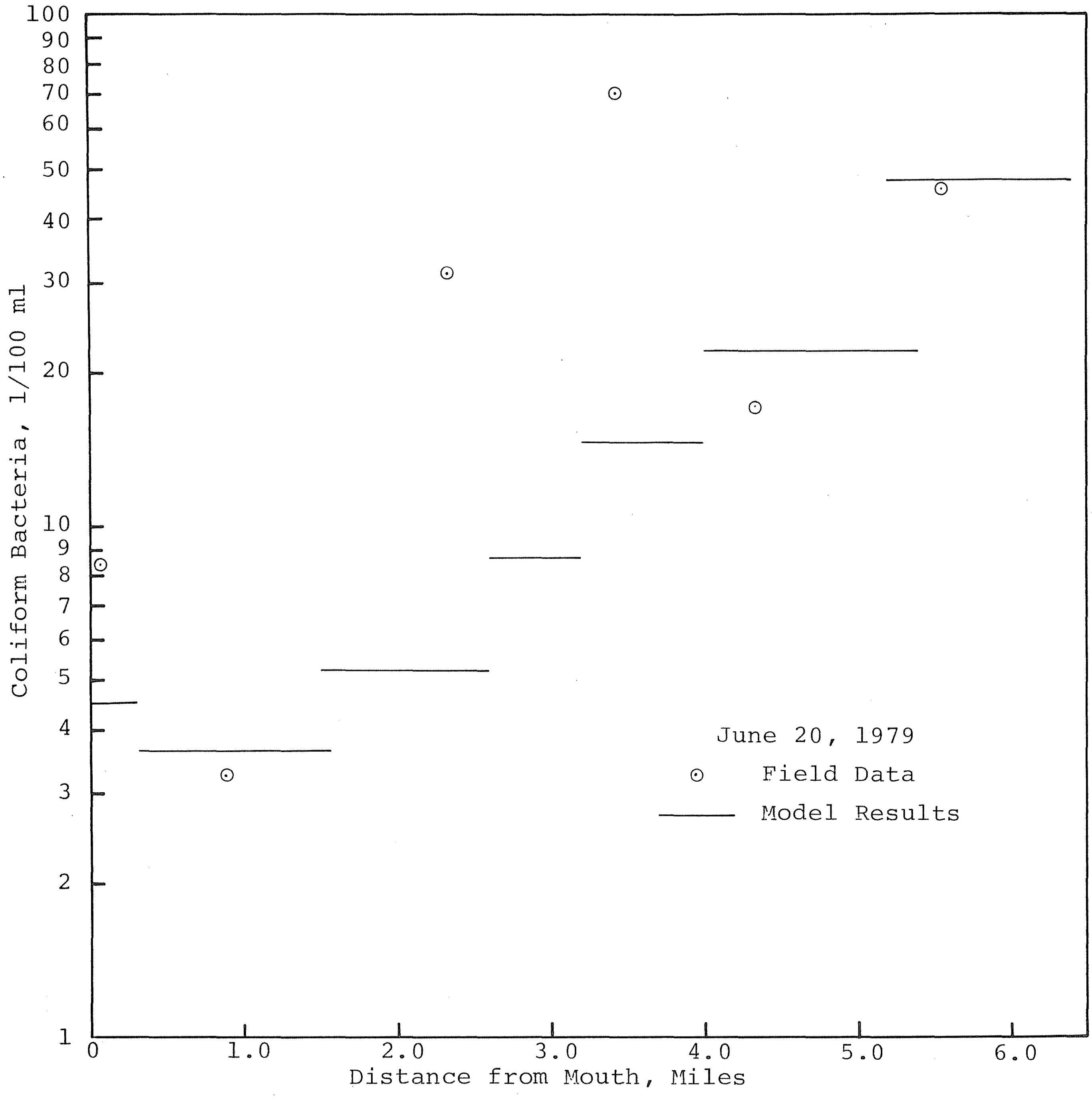

Figure 11. Coliform distribution on June 20, 1979.

The comparisons of TKN, CBOD and coliform data with model results indicate that there was a large amount of pollutants in the middle reach of the Bay which the model failed to simulate. This is most apparent in the TKN data for which the model reproduced observed distribution very well except in the reach between miles 3 and 4. The consequence of this discrepancy also shows up in DO distribution in which the model does not predict a concentration as low as field data indicate. This discrepancy is not the shortcoming of the water quality model, but is because the input data of pollutant source fails to represent accurately the actual conditions. However, it is not known whether this extra amount of pollutants is due to sources unaccounted for (e.g. septic tank seepage) or due to the failure of STORM model to accurately simulate nonpoint sources from runoff.

The model was also run to simulate the water quality conditions of August 13, 1979. The model results are compared with field data in Figures 12 to 15. The field data in Figure 15 show that DO is over-saturated in most parts of the Bay. It is therefore assumed that there was an algal bloom around August 13. The light extinction coefficient was reduced in the model simulation in order to simulate the high algal activities.

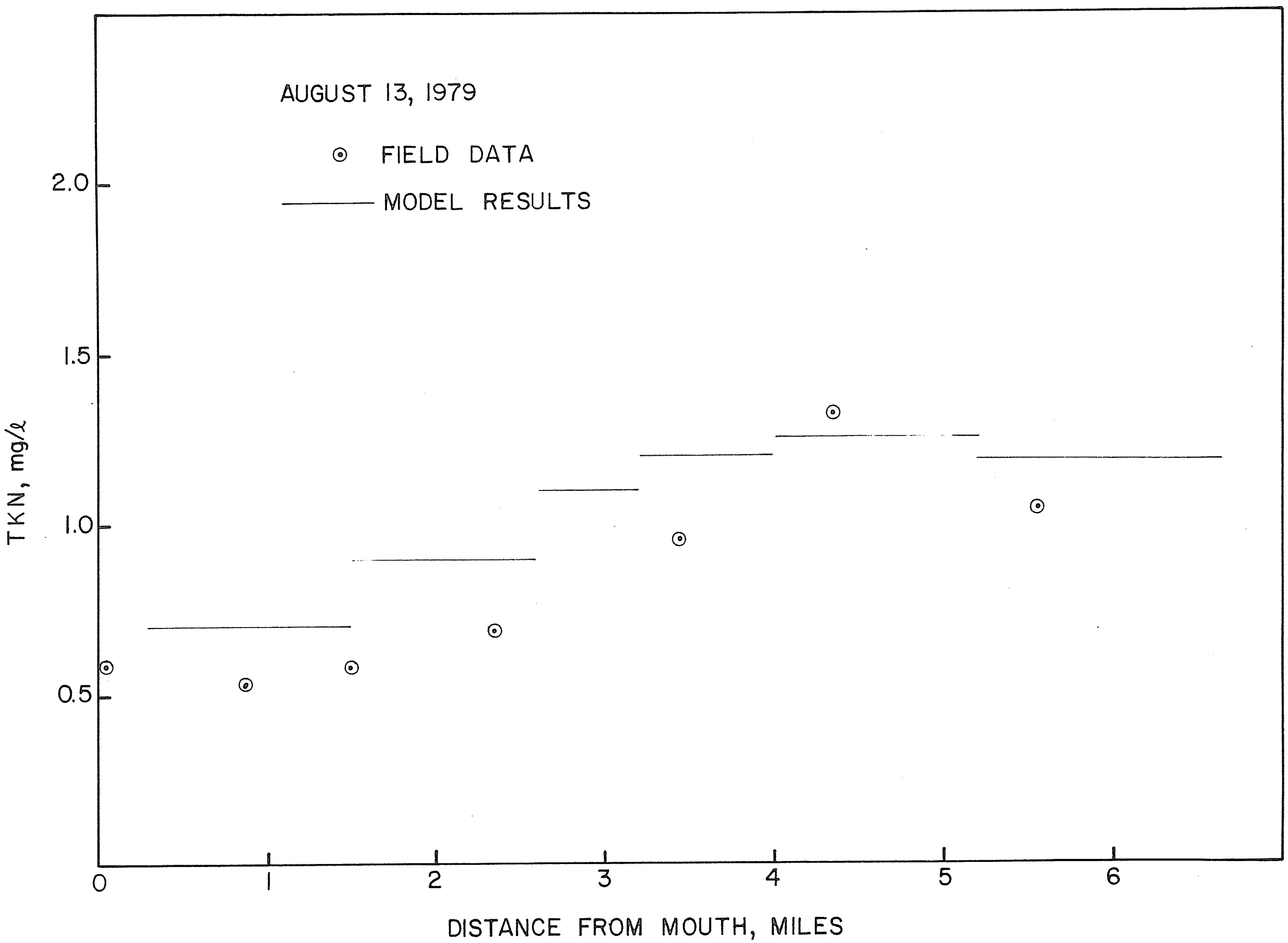

Figure 12. TKN distribution on August 13, 1979.

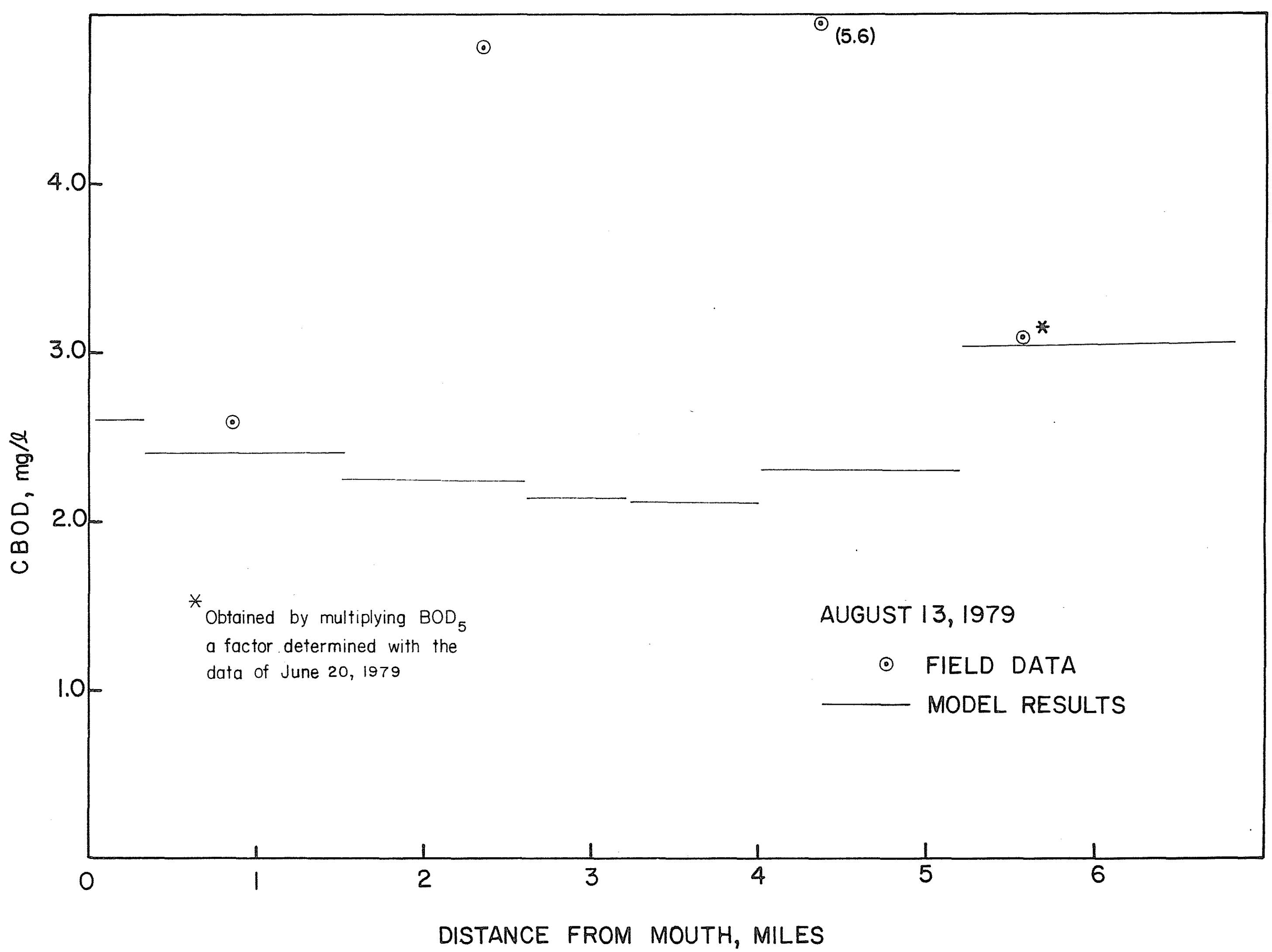

Figure 13. CBOD distribution on August 13, 1979.

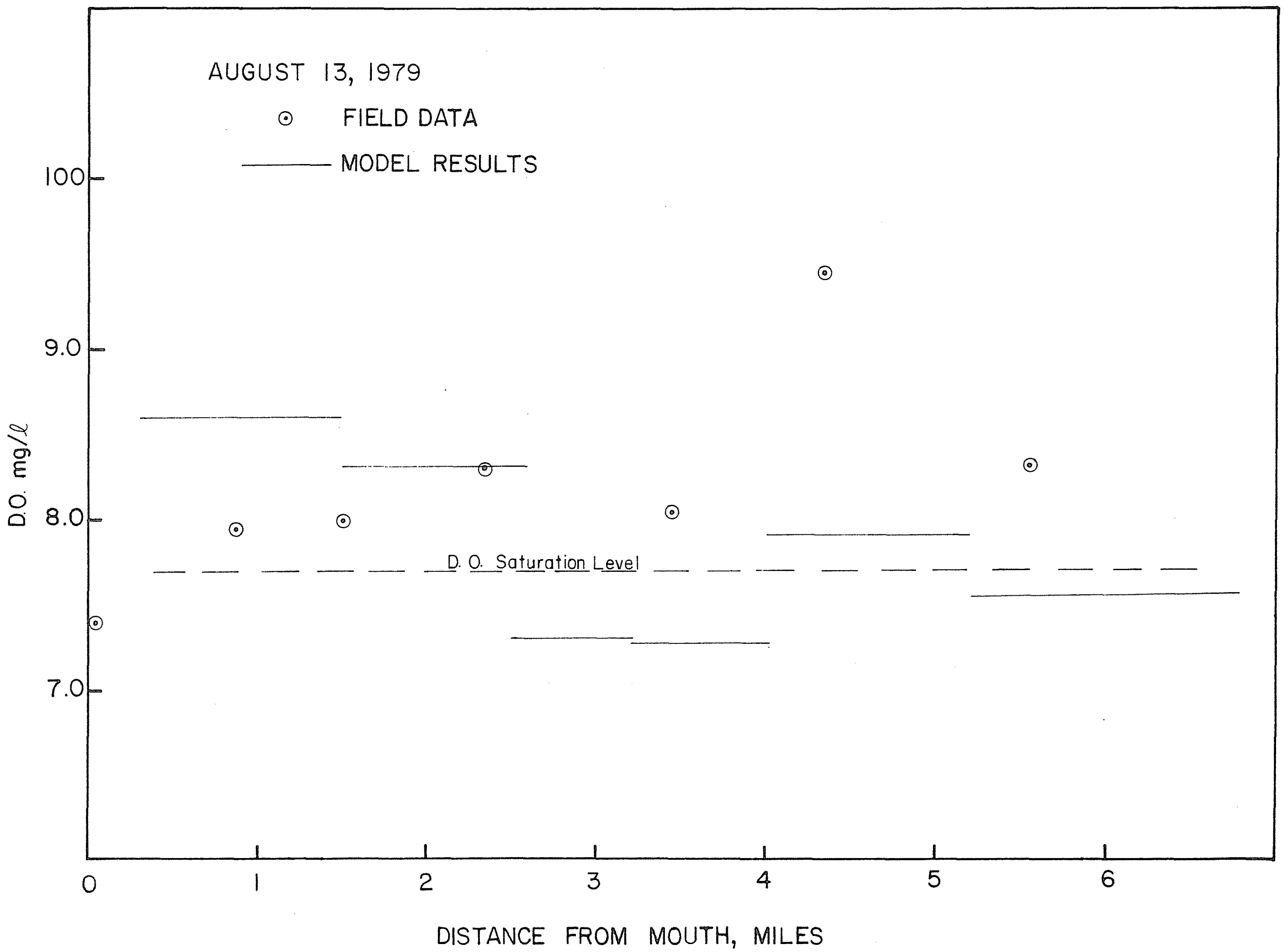

Figure 14. D.O. distribution on August 13, 1979.

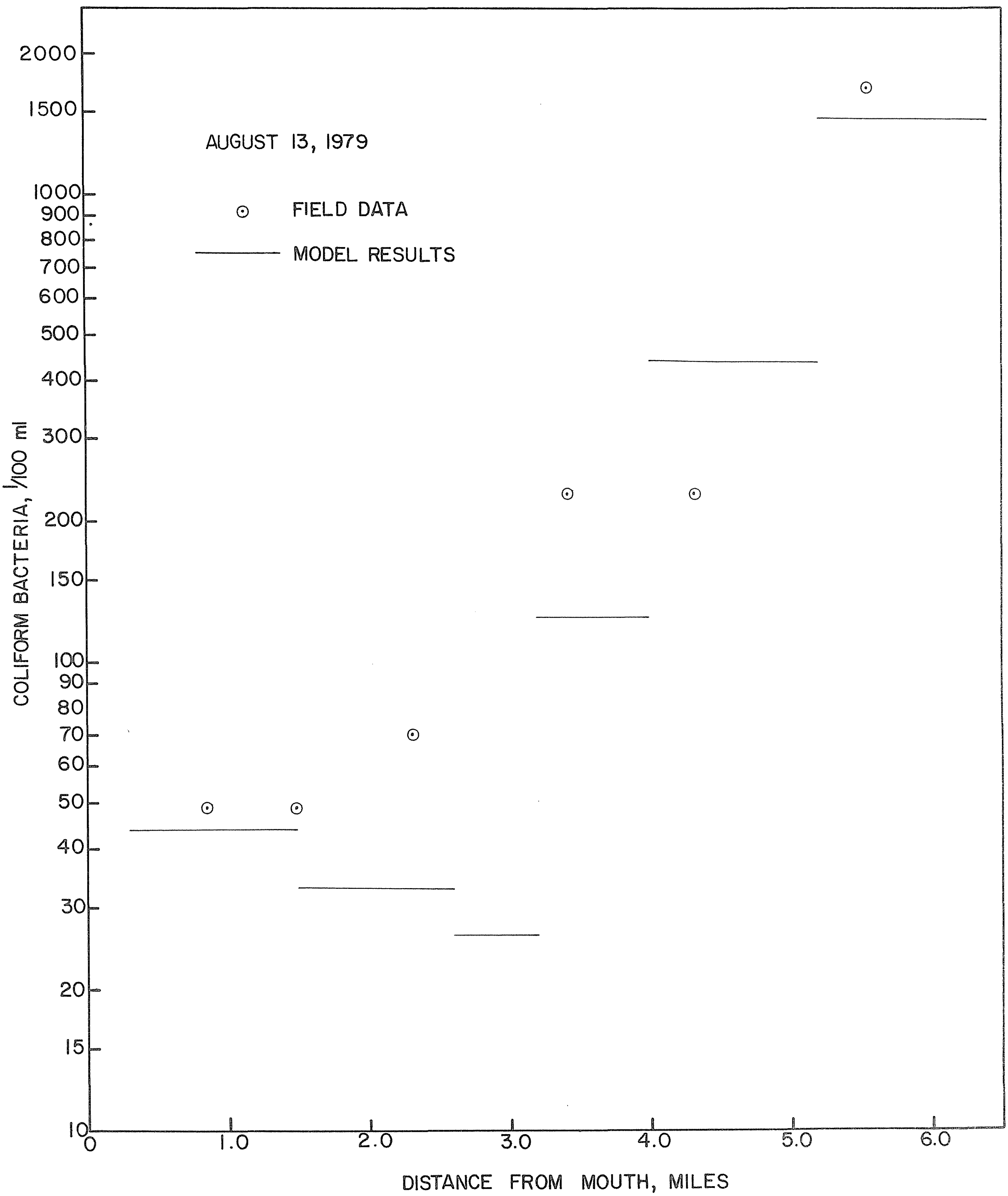

Figure 15. Coliform distribution on August 13, 1979.

B. Model Simulations

The model was used to project the water quality changes in the Bay which would be induced by the proposed canal improvement. A baseline condition was chosen for this study. The condition is the same as the one used for Hampton Roads 208 study (HRWQA final report, 1978, App. 5). The design storm selected for the '208' study was a sequence of rain events occurring in 1957, following a prolonged dry period. The rationale behind this selection was that pollutants would accumulate on land during the dry weather, then be washed off by the first or second rainfall in this sequence. It was found that the worst water quality conditions occurred after the first rainfall event of July 23-24, rather than after the greater rainfall of August 19-20. Therefore the following results are based on the July 23-24 event, which had a rainfall of 1.23 in. in 18 hours.

The STORM model was run to generate nonpoint source input for water quality model. The environmental conditions for the simulation were the same as 20 June 1979 simulation mentioned in previous section, except a higher water temperature of 28°C was used. Several simulations were performed to simulate the effect of canal improvement: (1) both the runoff and nonpoint source were increased by 30% to simulate the projected increase of freshwater discharge (House Document, 1976), (2) increase tidal prism by 20,000 m^3 plus (1), (3) increase tidal prism by 40,000 m^3 plus (1), and (4) increase tidal prism by 100,000 m^3 plus (1).

The results of model runs are summarized in Table 2. Except for dissolved oxygen, the first figure of each entry of the table is the concentration immediately after the storm and the second figure is that of one day after the storm. The maximum pollutant concentrations due to the storm runoff appear at the most upstream reach of the Bay immediately after the storm. The maximum impact on the Bay as a whole occurs sometime later, when the tidal flushing has spread the pollutant throughout the Bay. Since dissolved oxygen responds to pollutant loads through biochemical reaction, it takes about two days to reach its maximum depressed state. The dissolved oxygen distribution two days after the storm event is presented. The information in segment number 7 are excluded because it is a 'lumped' segment for which further segmentation is required in order to obtain accurate results. However, this is beyond the scope of the present study.

As indicated in Table 2, the canal improvement would have little impact on dissolved oxygen level in the Bay. However the model results show that the dissolved oxygen decreases from 4.95 mg/l to 4.93 mg/l in segment 7 due to the increase of nonpoint source. The increase in tidal prism increases DO in segment 7 above 5.0 mg/l. Even though these small changes of DO levels are within the error limit of the model, they do indicate qualitatively the effect of the canal improvement. Therefore, it is expected that further study for the extreme upstream portion would show some impact on DO level.

Table 2. Summarized Results of Model Simulations

Segment Number	Present Condition	Increase Runoff Only	Increase Runoff Plus Increase Tidal Prism by 20,000 m^3	40,000 m^3	100,000 m^3
Salinity, ppt					
2	21.1/21.0	21.1/21.0	21.1/21.2	21.1/21.2	21.1/21.2
3	20.9/20.9	20.8/20.9	20.9/21.1	20.9/21.1	20.9/20.9
4	20.8/20.5	20.8/20.3	20.9/20.2	20.9/20.0	20.9/19.7
5	20.3/18.5	20.0/17.6	19.3/16.8	18.7/16.7	16.7/16.8
6	11.2/14.4	6.9/13.0	8.0/14.5	8.9/15.3	11.4/16.8
Fecal Coliform, MPN/100 ml					
2	23.4/25.0	23.4/25.0	20.6/22.1	20.5/22.0	20.1/21.1
3	88.3/38.1	88.6/39.6	87.8/30.0	87.8/32.0	88.1/42.8
4	72.9/100	73.1/127	72.4/129	72.0/169	71.0/233
5	215/409	302/543	500/581	681/628	1200/712
6	2615/1119	3731/1353	3458/1389	3218/1210	2584/829
D.O., mg/l					
2	5.47	5.47	5.38	5.39	5.41
3	4.68	4.68	4.63	4.64	4.69
4	4.13	4.13	4.15	4.16	4.22
5	4.81	4.81	4.77	4.79	4.86
6	4.79	4.79	4.98	5.03	5.13
CBOD, mg/l					
2	1.73/1.74	1.73/1.74	1.74/1.74	1.75/1.74	1.76/1.76
3	1.62/1.59	1.62/1.60	1.65/1.59	1.66/1.61	1.68/1.68
4	1.44/1.58	1.44/1.64	1.47/1.75	1.49/1.83	1.52/1.97
5	1.49/2.17	1.61/2.50	1.95/2.83	2.24/2.87	3.04/2.90
6	5.00/3.61	6.66/4.14	6.28/3.72	5.93/3.44	5.03/2.89
TKN, mg/l					
2	0.49/0.49	0.40/0.50	0.49/0.48	0.49/0.48	0.49/0.49
3	0.52/0.51	0.52/0.51	0.51/0.49	0.51/0.49	0.51/0.51
4	0.52/0.55	0.52/0.57	0.51/0.58	0.51/0.60	0.51/0.63
5	0.57/0.75	0.61/0.83	0.67/0.91	0.74/0.91	0.94/0.91
6	1.50/1.15	1.93/1.29	1.82/1.15	1.72/1.07	1.48/0.89

Note: For D.O., the concentrations are those at two days after storm. For other parameters, the concentrations are those immediately and one day after storm (immediately after/one day after).

Table 2 also indicates that coliform bacteria, CBOD and TKN would increase in the upper half of the Bay as a result of canal improvement. The increase in tidal prism tends to shift the impact down the Bay. The increase in freshwater discharge and tidal prism have opposite impact on salinity. Freshwater discharge tends to suppress salinity while an increase in tidal prism brings in more saline water. The net effect depends on the relative magnitude of the two.

Since storm runoff is the only source of pollutants simulated in the model, the pollutant concentrations in the Bay would gradually decrease, if no additional precipitation occurs after the storm event. The reduction in pollutant concentrations is effected by physical transport (tidal flushing, freshwater runoff) and biochemical decay. The model was run to simulate the physical effect of canal improvement on the 'recovery' phase of the instream water quality. A conservative pollutant was introduced into each segment of the Bay in the same proportions as the pollutant generated by the design storm. After the storm, the model was run for another 40 tidal cycles without additional runoff. The time varying concentrations in segments 6 and 4 are presented in Figures 16 and 17 respectively. In each case, the concentration is normalized with respect to the maximum concentrations ever reached in that segment.

Figure 16 shows that maximum concentration appears in segment 6 immediately after storm event. The concentration

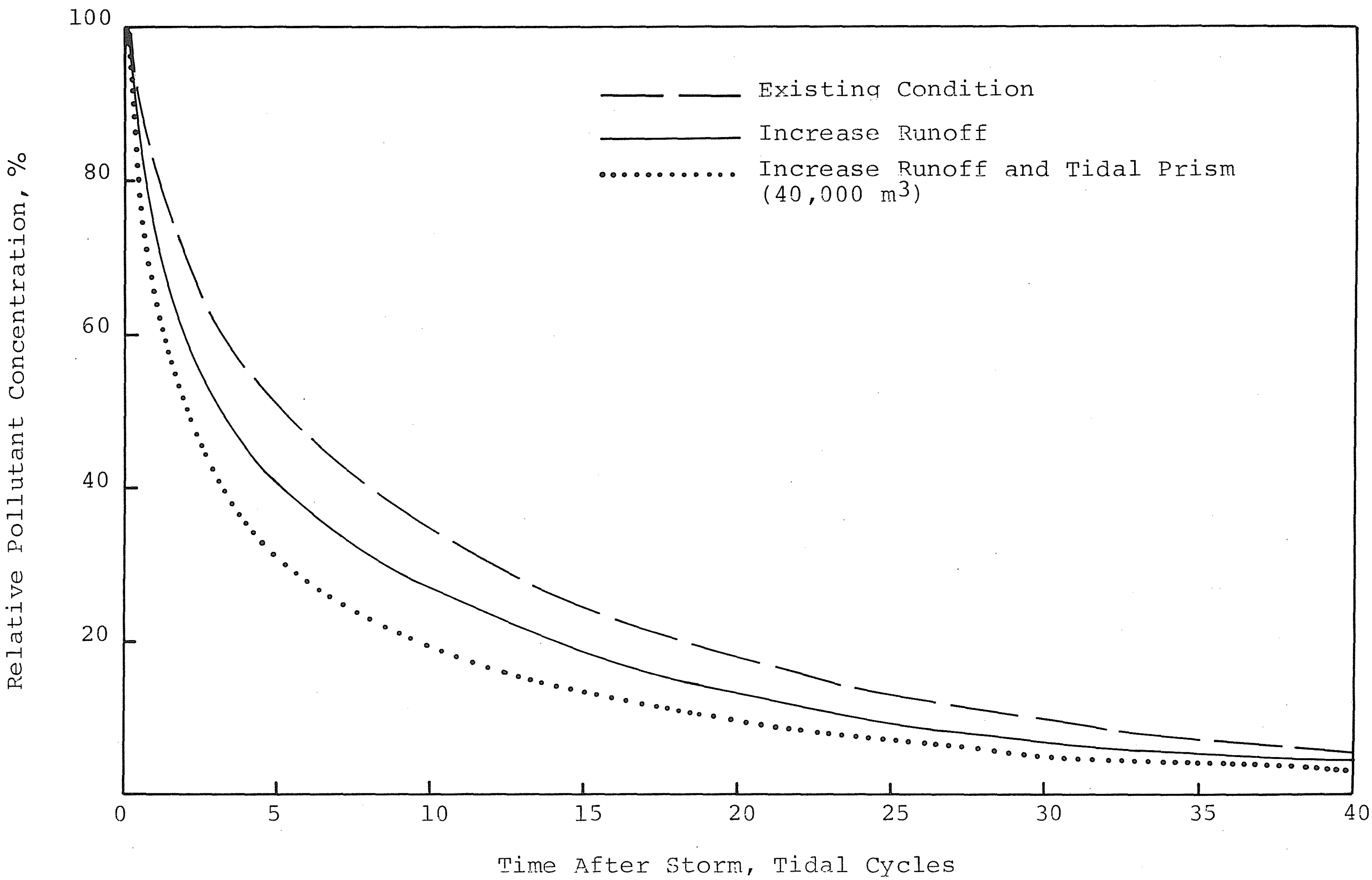

Figure 16. Flushing of Pollutant After Storm Event, Segment 6

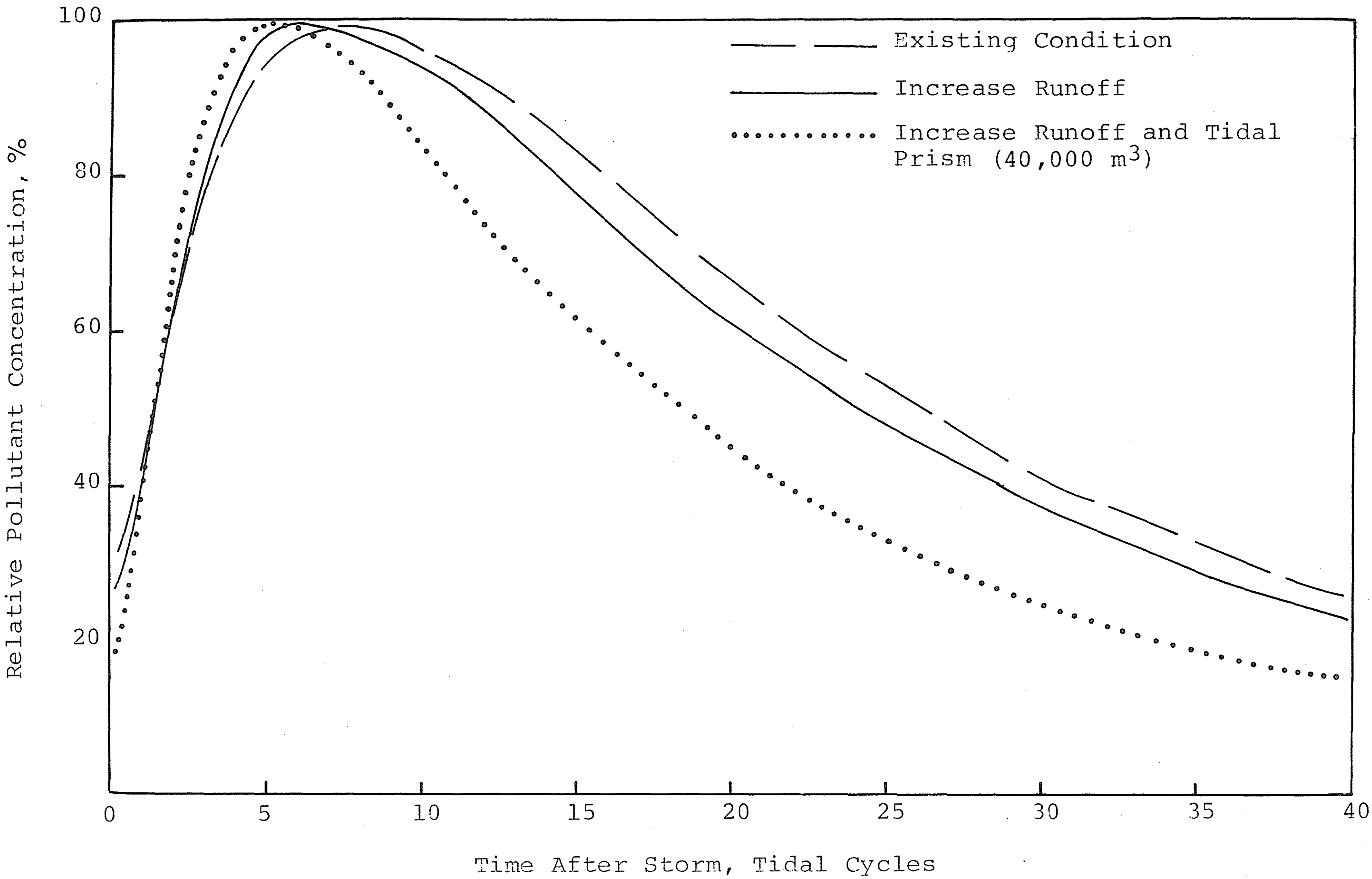

Figure 17. Flushing of Pollutant After Storm Event, Segment 4

decreases rapidly right after storm, and then the decreasing rate slows down gradually. Figure 17 indicates that the maximum concentration in segment 4 appears several tidal cycles after storm event, and then decreases with a rate slower than that of segment 6. The following table summarizes the time scales of 'recovery' phase of the Bay.

	Segment 6			Segment 4		
Conditions*	A	B	C	A	B	C
Peak Concentration (arbitrary unit)	4.69	6.54	5.74	0.57	0.68	0.90
Time of Peak Concentration (tidal cycles after storm)	0	0	0	8	6	5
Time for 50% Reduction (tidal cycles after peak)	5	3	2	18	18	13
Time for 90% Reduction (tidal cycles after peak)	30	24	20	>40	>40	>40

A: existing condition

B: increase runoff due to canal improvement

C: increase runoff plus increase tidal prism by 40,000 m^3

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