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A WATER QUALITY MODELING STUDY OF LYNNHAVEN BAY, VIRGINIA

by

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A Report to

Hayes, Seay, Mattern & Mattern, Inc.

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Summary

A mathematical water quality model was used to evaluate the effect of the proposed channel by the City of Virginia Beach on the water quality in the Eastern Branch of the Lynnhaven Bay. The model projection runs were made with nonpoint pollutant inputs prepared from the first storm event of the design storm sequence of the "Hampton Roads 208" study. The design storm was a sequence of rain events occurring in 1957, following a prolonged dry period.

The model simulations show that the proposed channel will depress dissolved oxygen slightly, with a maximum reduction of 0.15 mg/l at the upper reach of the Bay. This D.O. reduction is effected by the increased water depth and decreased tidal current, both of which tend to lower reaeration coefficient. The removal of bottom benthic oxygen demand by channel dredging may increase D.O. to slightly above existing conditions. However, this increase in D.O. is expected to diminish with time since detrital material is constantly added to the Bay. The concentrations of fecal coliform, biochemical oxygen demand and nutrients will be reduced as a result of the proposed channel dredging. This reduction is mainly effected by the increase in volume of the Bay which is more significant in the upper reach. The proposed channel will increase slightly the salinity of the Bay.

The proposed canal #2 will result in increases in the tidal prism and stormwater runoff. The increases in tidal prism and volume of runoff have a beneficial impact on water quality by improving the flushing of the Bay. However, the increase in nonpoint pollutant input tends to degrade the water quality. The combination of these effects, in addition to the proposed channel, will result in a slight increase of dissolved oxygen. The concentrations of fecal coliform, biochemical oxygen demand and nutrients would be at the same levels as existing condition if both the proposed channel and canal #2 are completed.

I. Introduction

The City of Virginia Beach has proposed channel dredging in the Eastern Branch of the Lynnhaven Bay for the purposes of recreations and drainage improvement. It is therefore necessary to examine the possible environmental results of such a project. This environmental assessment is complicated by another proposal to modify the Lynnhaven system. The U.S. Army Corps of Engineers has proposed adding a second canal leading to the Eastern Branch, in order to reduce flood damage. This canal project would affect the Lynnhaven system by increasing nonpoint sources of pollution and by increasing the tidal prism. The water quality consequences of the canal project have been studied (Kuo & Hyer, 1979). The proposed channel dredging project must be studied not only by itself but in combination with the canal project proposed by the Corps of Engineers.

In this study, the water quality model previously calibrated and validated for the Corps of Engineers is used to estimate the effects of the channel dredging in the Eastern Branch of the Lynnhaven.

II. Sources of Data

In the years 1976-1977, VIMS conducted a "208" study of the watersheds in Hampton Roads, with support from the EPA through the Hampton Roads Water Quality Agency. A water quality model of the Lynnhaven system was constructed, calibrated and verified (Ho, Kuo & Neilson, 1977). Input data for the model were collected by VIMS. Nonpoint source loadings were provided by Malcolm-Pirnie under the same project, using the STORM model.

The same water quality model was used for the present study. However, a new field program was undertaken (Kuo & Hyer, 1979) and the model extended and recalibrated. Additional field data were collected for this study. Three tide gauges were installed at stations 1, 6 and 7 (Figure 1) to record tidal variations simultaneously. The tidal prism upstream of station 6 was calculated from these tidal records. More benthic oxygen demands were measured to better quantify their magnitudes. The results are listed below:

Station	Date	Water Temperature °C	Benthic Oxygen Demand at 20°C, $gm/m^2/day$
2	June	26	1.2
4	June	25.5	1.6
	Oct.	24	1.3
	Nov.	17.1	1.4
5	Oct.	24.8	1.0
	Nov.	19	1.4
6	June	24	1.1
6A	Oct.	24.5	1.1

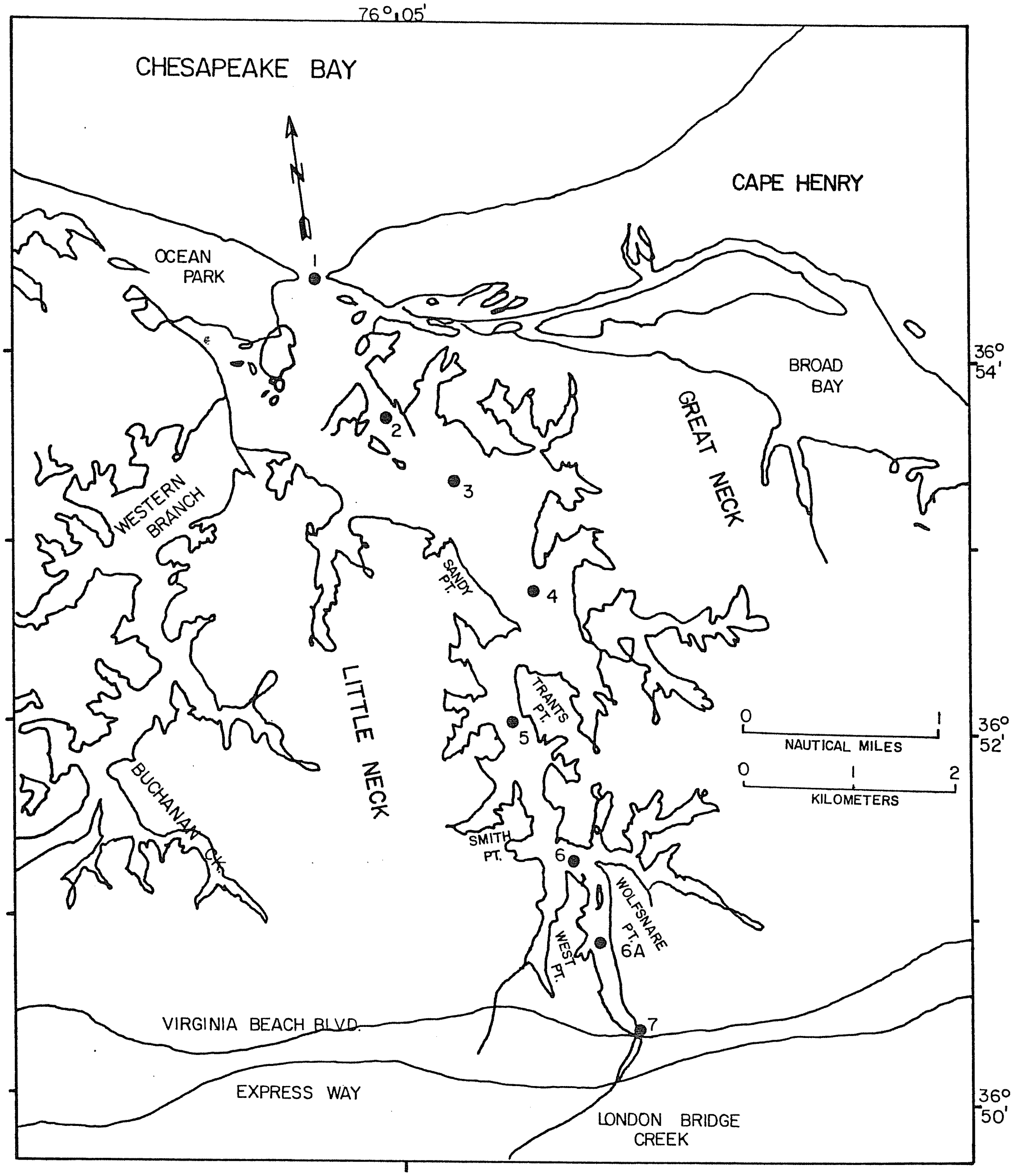

Figure 1. The Lynnhaven Bay showing sampling stations.

To generate nonpoint loadings for model calibration, the STORM model was run using the original constants but with 1979 precipitation records. For the projection runs reported herein, the "design storm" of the original "208" study was used to provide nonpoint loading calculations from the STORM model. 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. The major storms in the sequence occurred on July 23 and August 19 & 20, the later was a once-in-two-year event. (HRWQA Final Report, 1978, App. 5).

III. Description of Mathematical Model

The mathematical water quality model used in this study is a tidal-prism model, in which mixing and dilution caused by fresh water inflow and tidal exchange are simulated. The model contains salinity and fecal coliforms as independent submodels and eight other interdependent components comprising an ecosystem model. These components are: organic nitrogen, ammonia, nitrate plus nitrite, organic and inorganic phosphorus, chlorophyll (representing phytoplankton), dissolved oxygen, and ultimate carbonaceous biochemical oxygen demand. Figure 2 shows the flow diagram for the ecosystem model. A more complete description of the model may be found elsewhere (Ho, Kuo & Neilson, 1977).

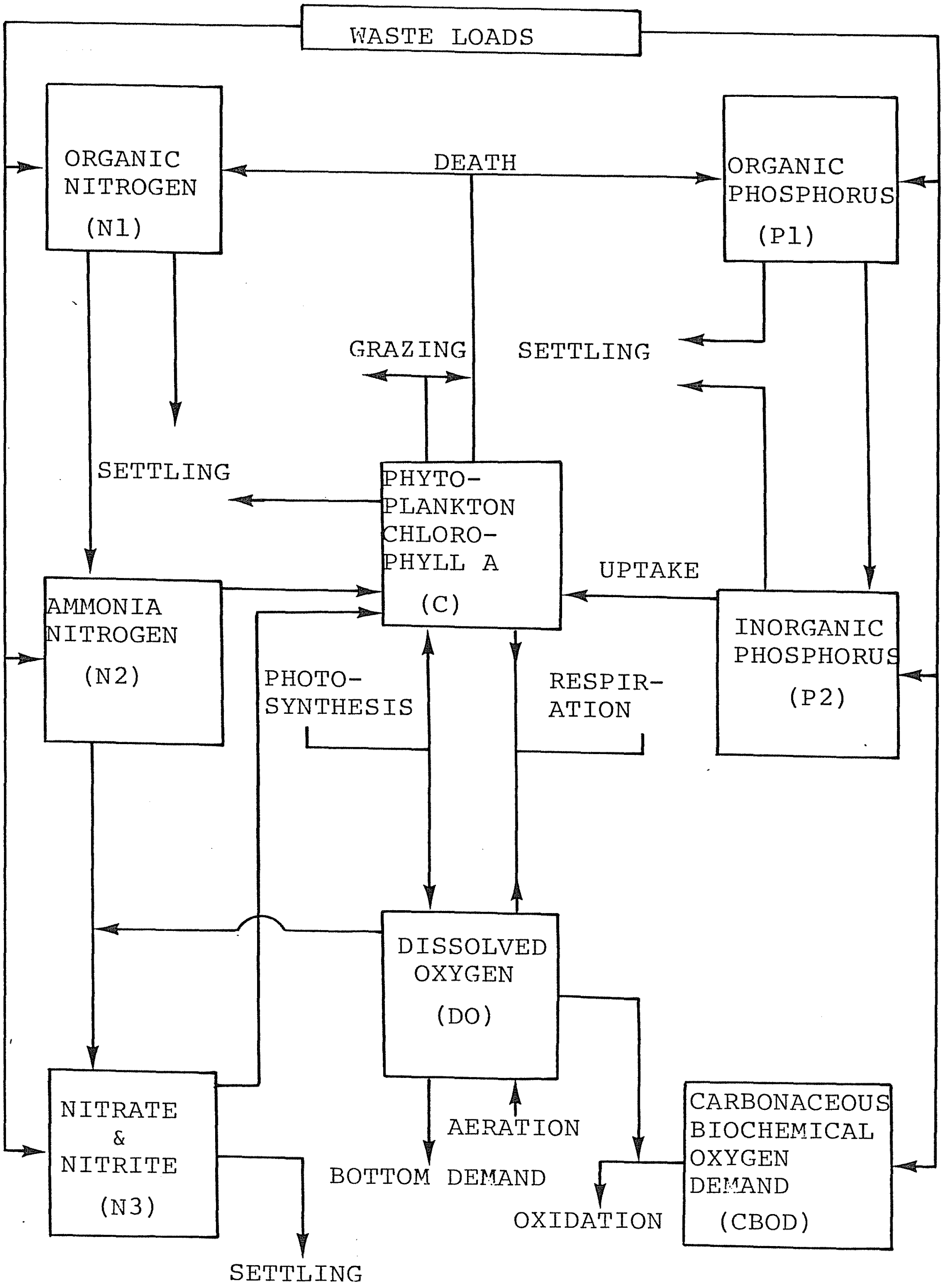

Figure 2. Flow diagram for ecosystem model.

IV. Results of Model Study

The model was segmented as shown in Figure 3. After model validation (Kuo & Hyer, 1979), a model projection run was made with inputs prepared from the storm events of the design storm sequence of the "208" study (HRWQA final report, 1978, App. 5). Since nonpoint sources depend on accumulation during dry weather (thirty days in these model runs), it was found that the worst water quality conditions occurred after the first rainfall event of July 23, rather than after the greater rainfall of Aug. 19-20. Therefore the conclusions following are based on the July 23 event, with the model run for 20 days beyond the storm event. Projection runs were made both for existing conditions and for conditions expected in 1995.

Model runs were made without any of the proposed projects and with modifications of input based on the proposed dredging projects. Two aspects of the proposed channel in the Eastern Branch (see Figure 3) were considered:

- change in geometric conditions caused by the increase in basin volume;
- reduction in bottom oxygen demand caused by removal of sediment.

The calculated percentage changes in high water volume and in bottom demand are shown in Table 1. For the

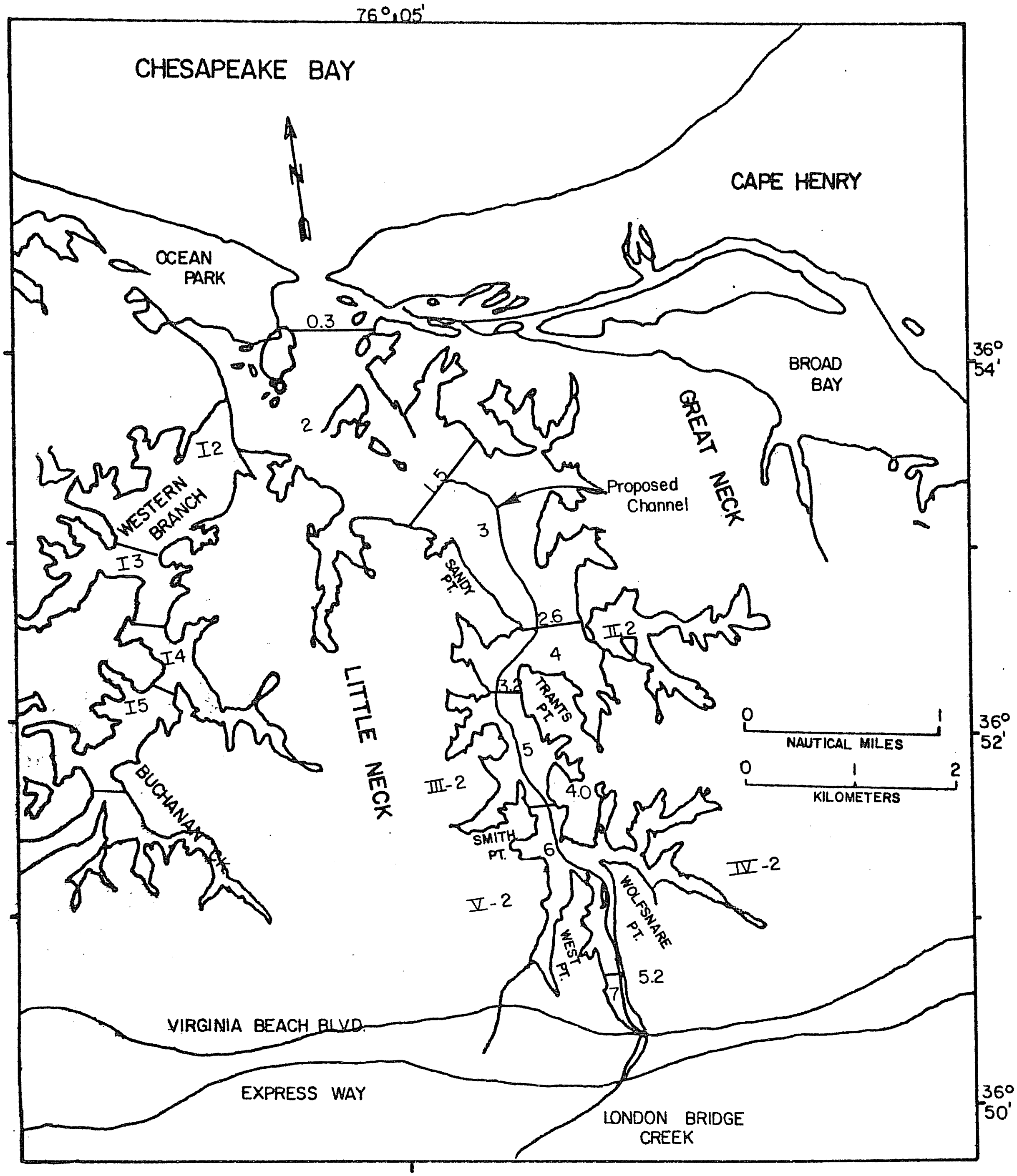

Figure 3. The Lynnhaven Bay showing the model segments and proposed channel.

Table 1

Changes in Model Inputs Due to Proposed Channel

Model Reach	Proposed Channel Increase in Volume ($ft^3 \times 10^6$)	Percent Change in High Water Volume	Percent Change in Sediment Oxygen Demand
2			
3	1.83	1.5	-1.4
4	0.60	0.9	-1.6
5	1.31	4.1	-3.7
6	4.28	26.4	-7.5
7	2.01	62.8	-89.3

bottom demand calculations, a uniform channel width of 70 feet and complete removal of sediment oxygen demand in that swath were assumed. The percent change in sediment oxygen demand is the percentage of the bottom area which is to be dredged. It is doubtful that this reduction in oxygen demand would be permanent, since detrital material is continually added (D. Boesch, pers. comm.). In any event, its effect on dissolved oxygen level is small.

A series of projection runs was made for existing conditions and for 1995 projections as follows:

1. unmodified channel;
2. with proposed channel;
3. with proposed channel & reduced sediment oxygen demand;
4. with proposed channel, reduced sediment oxygen demand and the effects of Canal #2;

The effects of Canal #2 to the Eastern Branch are twofold: increased tidal prism and increased nonpoint loading. To simulate these effects in model runs, the freshwater runoff and nonpoint pollutant input to segment 7 were increased by 30% and the tidal prism was increased by 40,000 m^3 (Kuo and Hyer, 1979).

The results of these simulation runs are shown in Tables 2 & 3 for present conditions and projected 1995 conditions respectively. The data for segment 7 are excluded because it is a "lumped" segment for which further segmentation is required in order to obtain accurate results. Except for dissolved oxygen, the first figure of each entry of the table is the concentration immediately

Table 2. Existing Conditions

Segment Number	Existing Condition	Modified Conditions*		
		A	B	C
Salinity, ppt				
2	21.1/21.0	21.1/21.0		21.1/21.1
3	20.9/20.9	20.8/20.9		20.9/21.0
4	20.8/20.5	20.8/20.6		20.9/20.9
5	20.3/18.5	20.6/19.3		20.0/18.4
6	11.2/14.4	14.8/15.7		10.9/13.6
Fecal Coliform, MPN/100 ml				
2	23.4/25.0	20.6/34.1		20.4/34.0
3	88.3/38.1	86.2/39.9		86.5/37.5
4	72.9/100	71.7/76.0		70.8/73.0
5	215/409	126/278		232/426
6	2615/1119	1617/876		2686/1243
D.O., mg/l				
2	5.47	5.47	5.47	5.40
3	4.68	4.66	4.70	4.66
4	4.13	4.11	4.19	4.23
5	4.81	4.77	4.86	4.94
6	4.79	4.64	4.82	4.96
CBOD, mg/l				
2	1.73/1.74	1.72/1.73		1.74/1.74
3	1.62/1.59	1.61/1.58		1.64/1.58
4	1.44/1.58	1.43/1.50		1.45/1.46
5	1.49/2.17	1.33/1.83		1.06/2.23
6	5.00/3.61	3.44/3.04		5.09/3.89
Organic Nitrogen, mg/l				
2	0.43/0.43	0.43/0.43		0.42/0.42
3	0.46/0.45	0.46/0.45		0.45/0.43
4	0.46/0.49	0.46/0.48		0.45/0.45
5	0.51/0.65	0.48/0.58		0.41/0.64
6	1.23/0.96	0.93/0.85		1.24/1.01
Ammonia Nitrogen, mg/l				
2	0.065/0.065	0.065/0.065		0.066/0.066
3	0.058/0.057	0.056/0.056		0.059/0.056
4	0.056/0.064	0.056/0.060		0.058/0.058
5	0.063/0.101	0.056/0.083		0.040/0.106
6	0.269/0.189	0.182/0.158		0.277/0.209

Table 2 (Cont'd)

Segment Number	Existing Condition	Modified Conditions*		
		A	B	C
Nitrate plus Nitrite Nitrogen, mg/l				
2	0.13/0.13	0.13/0.13		0.14/0.14
3	0.14/0.13	0.14/0.13		0.15/0.14
4	0.14/0.16	0.14/0.15		0.16/0.16
5	0.16/0.27	0.15/0.22		0.13/0.30
6	0.65/0.50	0.45/0.42		0.67/0.55
Organic Phosphorus, mg/l				
2	0.029/0.030	0.029/0.030		0.029/0.029
3	0.031/0.030	0.031/0.030		0.031/0.029
4	0.030/0.033	0.029/0.031		0.029/0.029
5	0.034/0.054	0.030/0.043		0.021/0.055
6	0.140/0.098	0.094/0.082		0.140/0.106
Inorganic Phosphorus, mg/l				
2	0.032/0.032	0.032/0.032		0.032/0.032
3	0.034/0.033	0.034/0.033		0.034/0.033
4	0.035/0.036	0.035/0.036		0.035/0.035
5	0.038/0.046	0.037/0.043		0.034/0.048
6	0.077/0.066	0.062/0.060		0.079/0.070

*A: with the proposed channel
B: with the proposed channel and a lower sediment oxygen demand
C: with the proposed channel, a lower sediment oxygen demand and the effects of Canal #2.

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

Table 3. Projected 1995 Conditions

Segment Number	Existing Condition	Modified Conditions*		
		A	B	C
Salinity, ppt				
2	21.1/21.0	21.1/21.0		21.1/21.1
3	20.8/20.8	20.8/20.9		20.8/21.0
4	20.8/20.2	20.8/20.7		20.8/20.7
5	19.6/17.6	20.6/18.8		19.6/17.5
6	8.0/13.0	10.5/13.6		7.7/12.0
Fecal Coliform, MPN/100 ml				
2	31.9/53.1	31.8/52.9		31.4/52.0
3	135/67.4	133/55.4		133/55.0
4	112/182	110/93.4		109/91.1
5	524/698	386/459		423/726
6	4406/1728	3536/1542		4465/1917
D.O., mg/l				
2	5.47	5.47	5.48	5.40
3	4.68	4.66	4.70	4.66
4	4.11	4.10	4.16	4.22
5	4.78	4.74	4.83	4.90
6	4.74	4.57	4.77	4.90
CBOD, mg/l				
2	1.74/1.76	1.73/1.76		1.75/1.75
3	1.68/1.64	1.66/1.60		1.69/1.59
4	1.48/1.75	1.47/1.52		1.49/1.57
5	1.90/2.81	0.84/2.22		1.25/2.89
6	7.50/4.86	6.17/4.49		7.57/5.28
Organic Nitrogen, mg/l				
2	0.43/0.44	0.43/0.44		0.43/0.42
3	0.47/0.46	0.47/0.46		0.46/0.44
4	0.48/0.53	0.47/0.49		0.46/0.48
5	0.60/0.79	0.39/0.67		0.45/0.80
6	1.77/1.24	1.51/1.18		1.79/1.33
Ammonia Nitrogen, mg/l				
2	0.065/0.066	0.065/0.066		0.067/0.067
3	0.061/0.059	0.061/0.057		0.062/0.057
4	0.059/0.073	0.059/0.062		0.060/0.064
5	0.087/0.139	0.029/0.107		0.051/0.146
6	0.415/0.264	0.343/0.247		0.422/0.292

Table 3 (Cont'd)

Segment Number	Existing Condition	Modified Conditions* A	B	C
Nitrate plus Nitrite Nitrogen, mg/l				
2	0.13/0.13	0.13/0.13		0.14/0.14
3	0.14/0.14	0.14/0.14		0.16/0.15
4	0.14/0.19	0.14/0.16		0.16/0.18
5	0.22/0.37	0.08/0.29		0.15/0.40
6	0.99/0.69	0.82/0.64		1.01/0.76
Organic Phosphorus, mg/l				
2	0.030/0.031	0.030/0.031		0.030/0.029
3	0.032/0.031	0.032/0.030		0.032/0.029
4	0.031/0.038	0.030/0.032		0.030/0.032
5	0.046/0.072	0.016/0.056		0.027/0.075
6	0.209/0.135	0.172/0.126		0.211/0.148
Inorganic Phosphorus, mg/l				
2	0.032/0.032	0.032/0.032		0.032/0.032
3	0.034/0.034	0.034/0.034		0.035/0.033
4	0.035/0.039	0.035/0.036		0.036/0.037
5	0.043/0.055	0.031/0.049		0.036/0.057
6	0.108/0.083	0.094/0.080		0.110/0.090

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*A: with the proposed channel
B: with the proposed channel and a lower sediment oxygen demand
C: with the proposed channel, a lower sediment oxygen demand and the effects of Canal #2.

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 in 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 time to spread the pollutant throughout the Bay.

Since dissolved oxygen responds to pollutant loading through biochemical reaction, it takes some time to reach its maximum depressed state. The dissolved oxygen concentrations presented in the table are those two days after the storm event. The tables show that the proposed channel (modified condition A) will reduce D.O. slightly because of the increased water depth and decreased tidal currents which result in lower reaeration coefficient. A maximum D.O. reduction of about 0.15 mg/l occurs at segment 6. The removal of bottom benthic oxygen demand (modified condition B) by channel dredging will increase D.O. to slightly above the existing condition. Since the area subjected to dredging is relatively small compared to the area of the Bay, the improvement is small, even if a 100% removal of benthic oxygen demand is assumed. The combined effect of increases in stormwater runoff and tidal prism due to Canal #2 tends to increase D.O. concentration, because both of them will increase current velocity, and thus, the reaeration coefficient.

The tables show that the fecal coliform concentrations will decrease as a result of the channel dredging. The concentration reduction is mainly effected by the increase in volume of the Bay which is more significant in the upper reach. The combination of the proposed channel and Canal #2 shows little change of fecal coliform concentration from existing condition.

The proposed channel will increase salt intrusion slightly. The combination of the proposed channel and Canal #2 suppresses salinity at the most upstream reach and has little impact on salinity in most parts of the Bay.

The impact on CBOD and nutrients show the same trends as those on fecal coliform. The proposed channel dredging will reduce CBOD and nutrient concentrations. The concentration reduction is most noticeable in the upstream reach. The effect of Canal #2 tends to lessen this impact.

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 4 and 5 respectively. In each case, the

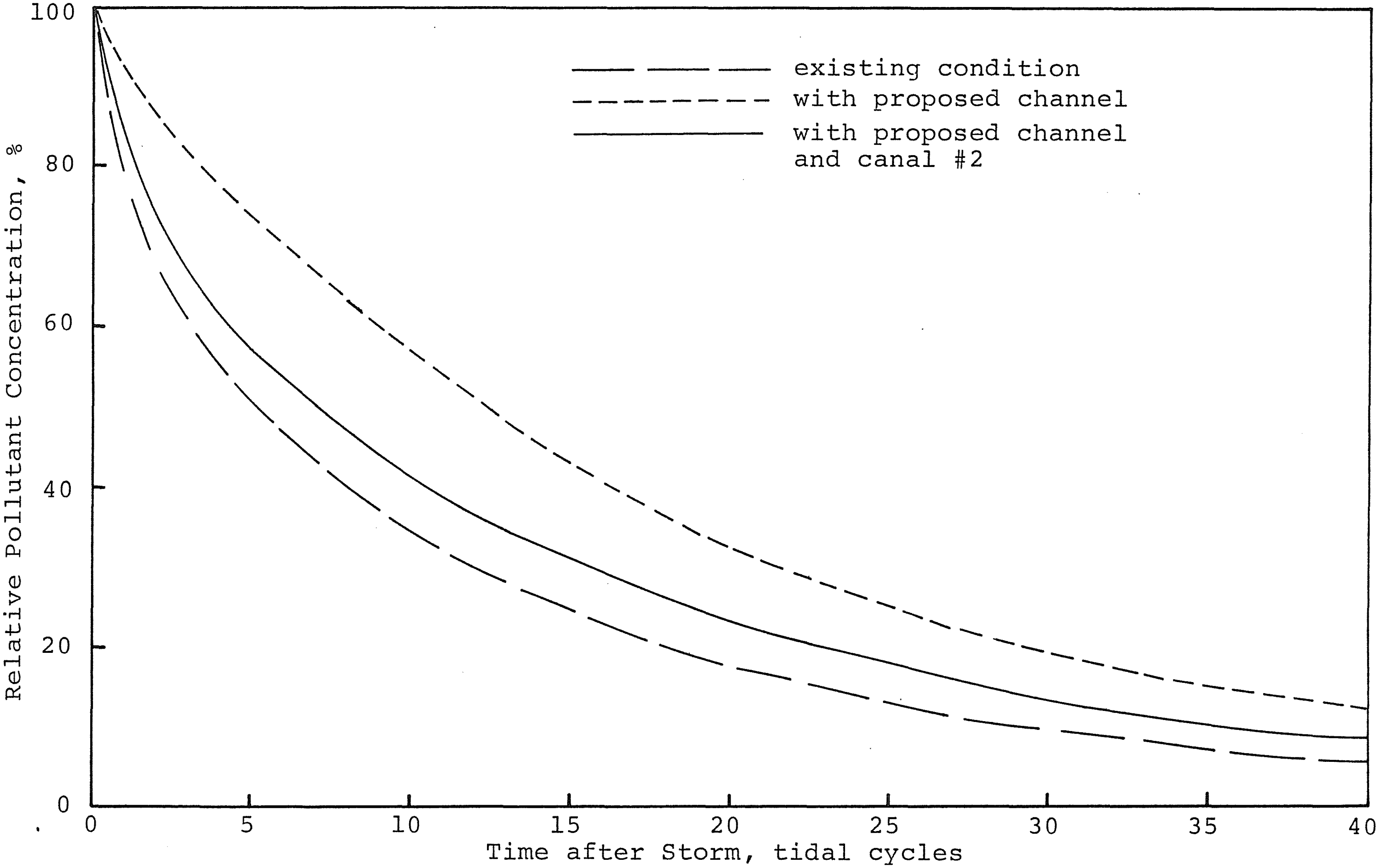

Figure 4. Flushing of pollutant after storm event, segment 6.

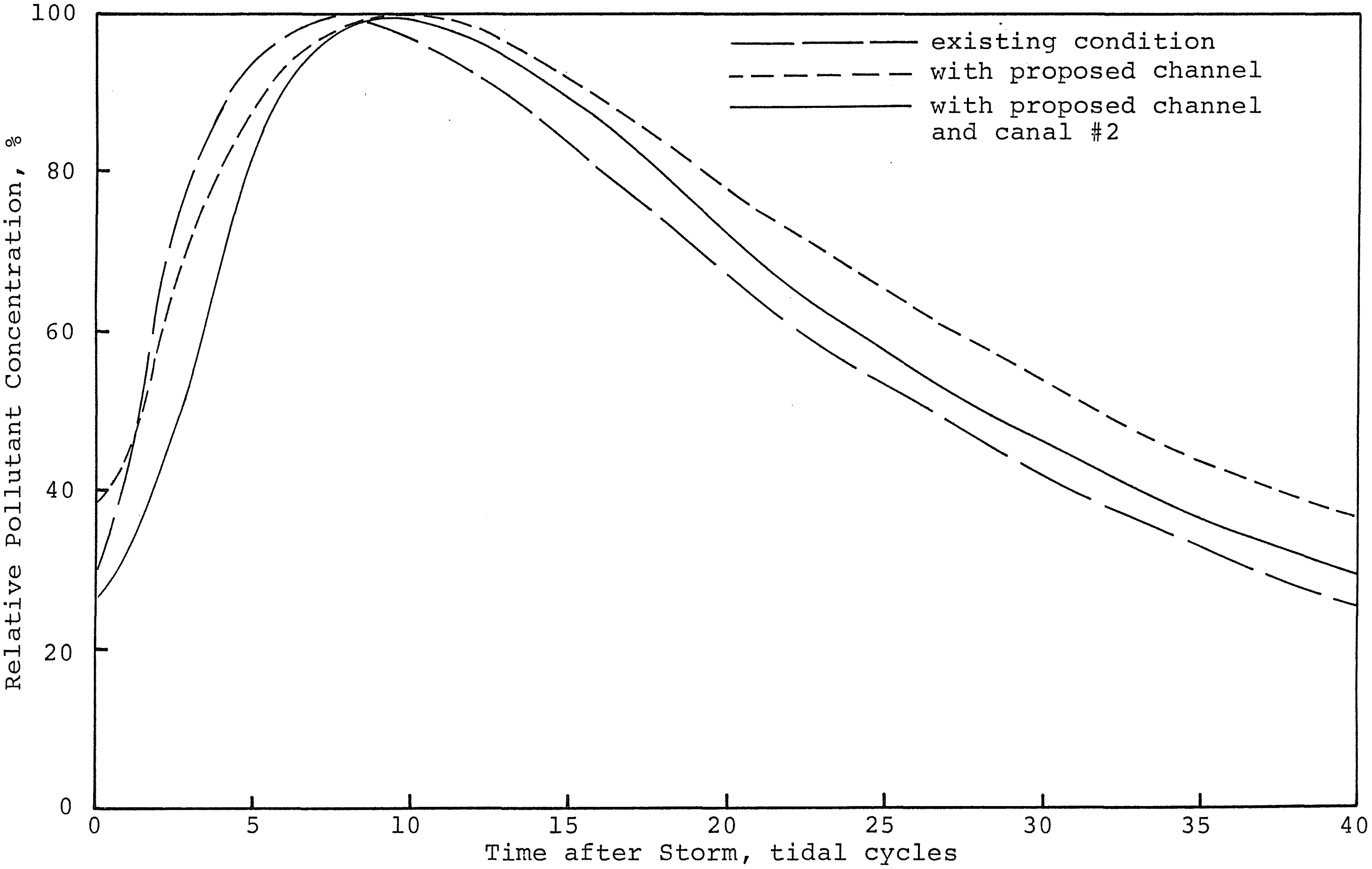

Figure 5. Flushing of pollutant after storm event, segment 4:

concentration is normalized with respect to the maximum concentrations ever reached in that segment.

Figure 4 shows that maximum concentration appears in segment 6 immediately after storm event. The concentration decreases rapidly right after storm, and then the decreasing rate slows down gradually. Figure 5 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	2.96	4.83	0.57	0.49	0.70
Time of Peak Concentration (tidal cycles after storm)	0	0	0	8	10	9
Time for 50% Reduction (tidal cycles after peak)	5	12	7	18	22	19
Time for 90% Reduction (tidal cycles after peak)	30	>40	35	>40	>40	>40

A: existing condition

B: with proposed channel

C: with proposed channel and Canal #2 (increase runoff and increase tidal prism by 40,000 m^3)

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