Report Version: December 8, 2000

APPENDIX A

Total Maximum Daily Loads of Nitrogen and Phosphorus for the Wicomico Creek Wicomico and Somerset Counties, Maryland

Appendix A

MODELING FRAMEWORK

The computational framework chosen for the modeling of water quality of the Wicomico Creek was the Water Quality Analysis Simulation Program version 5.1 (WASP5.1). This program provides a generalized framework for modeling contaminant fate and transport in surface waters (Di Toro *et al.*, 1983) and is based on the finite-segment approach. It is a very versatile program, capable of being applied in a time-variable or steady-state mode, spatial simulation in one, two or three dimensions, and using linear or non-linear estimations of water quality kinetics. To date, WASP5.1 has been employed in many modeling applications that have included river, lake, estuarine, and ocean environments. The model has been used to investigate water quality concerns regarding dissolved oxygen, eutrophication, and toxic substances. WASP5.1 has been used in a wide range of applications by regulatory agencies, consulting firms, academic researchers, and others.

WASP5.1 is supported and distributed by U.S. EPA's Center for Exposure Assessment Modeling (CEAM) in Athens, GA (Ambrose *et al.*, 1988). EUTRO5.1 is the component of WASP5.1 that is applicable for modeling eutrophication, incorporating eight water quality constituents in the water column (Figure A1) and sediment bed.

WATER QUALITY MONITORING

Physical and chemical samples were collected by MDE's Field Operations Program staff on February 18, March 11, April 1, July 28, August 24, and September 22, 1998. The physical parameters, dissolved oxygen, salinity, conductivity, and water temperature, were measured *in situ* at each water quality monitoring station. Grab samples were also collected for laboratory analysis. The samples were collected at a depth of ½ m from the surface. Samples were placed in plastic bottles and preserved on ice until they were delivered to the University of Maryland Laboratory in Solomons, MD or to the Department of Health & Mental Hygiene in Baltimore, MD for analysis. The field and laboratory protocols used to collect and process the samples are summarized in Table A1. The February, March, and April data were used to calibrate the water quality model of the Wicomico Creek during high flow conditions, and the July, August and September data were used to calibrate the water quality model during low flow conditions. Figures A2 – A9 present low flow and high flow water quality profiles along the creek. No BOD measurements were taken during high flow conditions.

INPUT REQUIREMENTS [1]

Model Segmentation and Geometry

The spatial domain of the Wicomico Creek Eutrophication Model (WCEM) extends from the confluence of the Lower Wicomico River and the Wicomico Creek for about seven miles to the creek's headwaters at the impound spillage of Allen Pond. Following a review of the bathymetry for Wicomico Creek, the model was divided into seven segments. Figure A10 shows the model segmentation for the development of the WCEM. Table A2 lists the volumes, characteristic lengths, and interfacial areas of the seven segments.

Dispersion Coefficients

The dispersion coefficients were calibrated using the WASP5.1 model and in-stream water quality data from 1998. The WASP5.1 model was set up to simulate salinity. Salinity is a conservative constituent, which means there are no losses due to reactions in the water. The only source in the system is at the tidal boundary at the mouth of the creek. For the model execution, salinities at all boundaries except the tidal boundary were set to zero. Flows were obtained from three USGS gages near the basin (see the following section on freshwater flows for more detail). Figure A11 shows the results of the calibration of the dispersion coefficients for low flow. The same sets of dispersion coefficients were used for both the high flow and low flow model calibrations because of insufficient salinity data during high flow periods. Final dispersion coefficients are listed in Table A3.

Freshwater Flows

Freshwater flows were calculated on the basis of delineating the Wicomico Creek drainage basin into five subwatersheds (Figure A12). These subwatersheds closely correspond to the Maryland Department of Natural Resources 12-digit basin codes. As necessary, the subwatersheds were refined to assure they were consistent with the seven segments developed for the WCEM. The WCEM was calibrated for two sets of flow conditions: high flow and low flow. The high flow corresponds to the months of February, March, and April, while the low flow corresponds to the months of July, August, and September.

The high flows for the subwatersheds were estimated using an average flow from the months of February, March, and April of 1998 from the USGS gages #0148500, #0148550, and #0148600 located near the Wicomico Creek Basin. The flow data from the USGS gage #0148650, located in the Wicomico River Basin, was not used because it was closed in 1975. A ratio of flow to drainage area was calculated and then multiplied by the area of the subwatersheds to obtain the

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1 The WASP model requires all input data to be in metric units, and to be consistent with the model, all data in the Appendix will appear in metric units except the stream length. Following are several conversion factors to aid in the comparison of numbers in the main document: mgd x (0.0438) = m^3s | cfs x (0.0283) = m^3s | lb / (2.2) = kg | mg/l x mgd x (8.34) / (2.2) = kg/d |

high flows. During high flow, each subwatershed was assumed to contribute a flow to the Wicomico Creek.

The low flows for the subwatersheds were also estimated based on the flow to drainage area ratio of the three USGS gages as described above, but using flow data from the months of July, August, and September of 1998. It was assumed that during summer, flow was only draining to those model segments that receive free-flowing streams.

The average flows were estimated based on the flow to drainage area ratio of the three USGS gages, this time averaging the flow data from January 1984 through December 1987. Table A4 presents the flows for the subwatersheds during high, low, and average flows.

Point and Nonpoint Source Loadings

There are no point sources contributing loads to the Wicomico Creek. Nonpoint source loadings were estimated for low flow, high flow, and average annual flow conditions. Loads for low flow and high flow conditions were calculated from the product of observed concentrations and the respective estimated flows. These loads account for all sources because they are observed loads.

Concentrations for the determination of loads for the calibration of the model for both high flow and low flow were calculated using in-stream data from various monitoring stations within the Lower Wicomico River basin. Averaged data from stations WIW0050 and WIW0105, located near the confluence of the Wicomico Creek with the Lower Wicomico River, was used as the boundary concentration for segment one, and data from station WIC0073 was used as a boundary concentration for segment seven. The boundary concentrations for the remaining non-tidal boundaries were based on average data from stations ADW0001, LPR0020, and WIW0241. These three stations were assumed to reasonably represent water quality for the remaining non-tidal boundaries and were used because data for free-flowing streams was not available within the Wicomico Creek drainage basin. BOD data was not available for high flow and was assumed to be 2.0 mg/l at all boundaries.

Average annual loads were determined using land use loading coefficients. The land use information was based on 1997 Maryland Office of Planning land use/land cover data, adjusting crop acres using 1997 Farm Service Agency (FSA) data. The total nonpoint source load was calculated by summing all of the individual land use areas and multiplying by the corresponding land use loading coefficients. The loading coefficients were based on the results of the Chesapeake Bay Model (U.S. EPA, 1996), a continuous simulation model. The Bay Model loading rates are consistent with what would be expected in the year 2000 assuming continued Best Management Practice (BMP) implementation at a level consistent with the current rate of progress. These loads reflect both natural and human sources, including atmospheric deposition, loads coming from septic tanks, and loads stemming from urban development, agriculture, and forestland.

For nonpoint sources, the concentrations of the nutrients nitrogen and phosphorus are modeled in their speciated forms. The WASP5.1 model simulates nitrogen as ammonia (NH_3), nitrate and nitrite (NO_{23}), and organic nitrogen (ON); and phosphorus as ortho-phosphate (PO_4) and organic phosphorus (OP). Ammonia, nitrate and nitrite, and ortho-phosphate represent the dissolved forms of nitrogen and phosphorus. The dissolved forms of nutrients are more readily available for biological processes, such as algae growth, that can affect chlorophyll *a* levels and dissolved oxygen concentrations. The ratios of total nutrients to dissolved nutrients used in the model scenarios represent values that have been measured in the field.

Environmental Conditions

Eight environmental parameters were used for developing the model of the Wicomico Creek: solar radiation, photoperiod, temperature (T), extinction coefficient (K_e), salinity, sediment oxygen demand (SOD), sediment ammonia flux (FNH_4), and sediment phosphate flux (FPO_4) (Tables A5 & A6).

The light extinction coefficient, K_e, in the water column was derived from Secchi depth measurements using the following equation:

$$K_e = \frac{1.95}{D_s}$$

where:

K_e = light extinction coefficient (m^{-1})
D_s = Secchi depth (m)

It was estimated that nonliving organic nutrient components as well as phytoplankton settle from the water column into the sediment at an estimated settling rate velocity of 0.0086 m/day. In general, it is reasonable to assume that 40% of the nonliving organic nitrogen, organic phosphorus, and BOD, and 30% of the ortho-phosphate are in the particulate form. Such assignments were borne out through model sensitivity analyses.

Different SOD values were estimated for different WCEM reaches based on observed environmental conditions and literature values (Institute of Natural Resource, 1986). The highest SOD values were assumed to occur in the lower reaches, where a maximum SOD value of 2.4 g O_2/m^2day was used.

Kinetic Coefficients

The water column kinetic coefficients are universal constants used in the WCEM model. They are formulated to characterize the kinetic interactions among the water quality constituents. The initial values were taken from past modeling studies of the Potomac River (Clark and Roesh, 1978; Thomann and Fitzpatrick, 1982; Cerco, 1985), and of Mattawoman Creek (Panday and Haire, 1986, Domotor *et al*., 1987), and the Patuxent River (Lung, 1993). The kinetic coefficients are listed in Table A7.

Initial Conditions

The initial conditions used in the model were chosen to reflect the observed values as closely as possible. It was found, however, that initial conditions did not impact the final results because the model simulated a long period of time (300 days) to reach equilibrium.

CALIBRATION & SENSITIVITY ANALYSIS

The EUTRO5.1 model for low flow was calibrated with July, August and September 1998 data. Tables A8 – A11 show the nonpoint source flows and loads associated with the calibration input files. Figure A13 shows the results of the low flow calibration of the model. As can be seen in the Figure, the model did a good job of capturing the general trend of most state variables, although it did not always capture the peak values. The model did an excellent job of capturing both the peak concentrations and trends of dissolved oxygen, ammonia, organic nitrogen, and organic phosphate.

The EUTRO5.1 model for high flow was calibrated with February, March, and April 1998 data. The results are presented in Figure A14. As can be seen, the model captured the trends of most of the state variables. The model failed to capture organic phosphorus and nitrate/nitrite; however, this is not very significant given that the range of values is very small. The model also failed to capture the peak chlorophyll *a* values; however, this is not significant given the range of values.

SYSTEM RESPONSE

The EUTRO5.1 model of Wicomico Creek was applied to several different nonpoint source loading conditions under various stream flow conditions to project the impacts of nutrients on algal production, represented by chlorophyll *a*, and low dissolved oxygen. By simulating various stream flows, the analysis accounts for seasonality.

Model Run Descriptions

The first scenario represents the expected conditions of the creek under current loading conditions during low flow. The low flow was estimated using three USGS gages near the basin as described above. The total nonpoint source loads were computed as the product of observed 1998 base-flow concentrations and the estimated low flow. These loads account for all background and human-induced sources because they are based on observed concentrations. All environmental parameters used for scenario 1 remained the same as for the low flow calibration.

The second scenario represents the expected conditions of the creek during average flow. The average annual flow was estimated based on data from three USGS gages near the Wicomico Creek basin as described above. Nonpoint source load estimation methods, based on EPA Chesapeake Bay model output, are described above. All the environmental parameters, except the water temperature, remained the same. A summer average temperature of 25.9 ^{o}C was used for all segments, which is a conservative value. The boundary and initial condition values for CHL*a*, DO, and BOD were assumed to be the same as for scenario 1. The nonpoint source loads for model scenarios 1 and 2 can be seen in Table A12 and Table A13 respectively.

A number of iterative model scenarios involving nutrient reductions were explored to determine the maximum allowable loads. The third and fourth scenarios show the water quality responses in the creek for the maximum allowable loads for low flow and average annual flow respectively. To estimate feasible nitrogen and phosphorus nonpoint source reductions, the percent of the load that is controllable was estimated for each subwatershed. It was assumed that the loads stemming from cropland, feedlots, and urban areas were controllable and that loads from atmospheric deposition, septic tanks, pasture, and forest were not controllable. This analysis was performed on the average annual loads only because data for loads contributed by specific land uses were not available for low flow. The percent controllable, however, was applied to both the low flow loads and the average annual loads.

For the scenario runs where the nutrient loads to the system were reduced, a method was developed to estimate the reductions in nutrient fluxes and SOD from the sediment layer. First, for each segment, an initial estimate was made of the total organic nitrogen and organic phosphorus settling to the stream bottom from particulate nutrient organics, living algae, and phaeophytin. This was done by running the base-line condition scenario once with estimated settling of organics and chlorophyll *a* and again with no settling. The difference in the organic matter between the two runs was assumed to settle to the stream bottom where it would be available as a source of nutrient flux and SOD. All phaeophytin was assumed to settle to the bottom. The amount of phaeophytin was estimated from in-stream water quality data. To calculate the organic loads from the algae, it was assumed that the nitrogen to chlorophyll *a* ratio was 12.5 and that the phosphorus to chlorophyll *a* ratio was 1.25. This analysis was then repeated for the reduced nutrient loading conditions. The percentage difference between the amount of nutrients that settled in the base-line condition scenarios and the amount that settled in the reduced loading scenarios was then applied to the nutrient fluxes in each segment. The reduced nutrient scenarios were then run again with the updated fluxes. A new value of settled organics was calculated, and the fluxes were updated. The process was repeated until the reduced fluxes remained constant.

Along with reductions in nutrient fluxes from the sediments, when the nutrient loads to the system are reduced, the sediment oxygen demand will also be reduced (US EPA, 1997). It was assumed that the SOD would be reduced in the same proportion as the nitrogen fluxes, to a minimum of 0.5 gO_2/m^2 day.

The third scenario represents improved conditions associated with the maximum allowable loads to the stream during critical low flow. The flow was the same as in scenario 1. A margin of safety of 5% was included in the load calculation. The nitrogen and phosphorus loads were reduced from the scenario 1 base-line to meet the chlorophyll *a* goal of 50 *m*g/l and the dissolved oxygen criterion of no less than 5.0 mg/l. All environmental parameters (except nutrient fluxes and SOD) and kinetic coefficients used for the calibration of the model remained the same as in scenario 1.

The fourth scenario represents improved conditions associated with the maximum allowable loads to the stream during average annual flow. The flow was the same as in scenario 2. The nitrogen and phosphorus loads were reduced from the scenario 2 base-line to meet chlorophyll *a* and dissolved oxygen standards as in scenario 3. A 3% margin of safety was included in the load calculation. All environmental parameters (except nutrient fluxes and SOD) and the kinetic coefficients used for the calibration of the model remained the same as in scenario 2.

For all scenarios, the boundary conditions at the confluence of the Wicomico Creek and the Wicomico River reflect the average in-stream conditions for the respective flow regimes of stations WIW0050 and WIW0105, which are located near the confluence in the Wicomico River. No reductions were applied to this boundary.

Scenario Results

Base-line Loading Condition Scenarios:

1. *Flow:* Simulates critical low stream flow conditions during summer season. Water quality parameters (e.g., nutrient concentrations) are based on 1998 observed data.

2. *Average Annual Flow:* Simulates average stream flow conditions, with average annual nonpoint source loads estimated based on 1997 land use and projected year 2000 nutrient loading rates from the EPA Chesapeake Bay watershed model.

The WCEM calculates the daily average dissolved oxygen concentrations in the stream. This is not necessarily protective of water quality when one considers the effects of diurnal dissolved oxygen variation due to photosynthesis and respiration of algae. The photosynthetic process centers about the chlorophyll containing algae that utilize radiant energy from the sun to convert water and carbon dioxide into glucose and release oxygen. The production of oxygen proceeds only during daylight hours because the photosynthetic process is dependent on solar radiant energy. Concurrently with this production, however, the algae require oxygen for respiration, which can be considered to proceed continuously. Minimum values of dissolved oxygen usually occur in the early predawn hours when the algae have been without light for the longest period of time, whereas maximum values of dissolved oxygen usually occur in the early afternoon. The diurnal range (maximum minus minimum) may be large, and if the daily mean level of dissolved oxygen is low, minimum values of dissolved oxygen during a day may approach zero and hence create a potential for fish kill. The diurnal dissolved oxygen variation due to photosynthesis and respiration is calculated by the WCEM based on the amount of chlorophyll *a* in the water. For the rest of the model results, the minimum dissolved oxygen concentration is reported.

Results for scenario 1, which represent base-line summer low flow conditions, are summarized in Figure A15. As can be seen, the peak chlorophyll *a* level is above the desired threshold of 50 *m*g/l, reaching a maximum value of about 57*m*g/l. The dissolved oxygen concentrations, however, are not expected to fall below the minimum water quality criterion of 5 mg/l.

Results for scenario 2, which represent base-line conditions for average stream flow and loads, are summarized in Figure A16. Under these conditions, the chlorophyll *a* concentrations are well above the desired goal of 50 *m*g/l, and the dissolved oxygen concentrations remain above the 5 mg/l criterion throughout the length of the creek.

Future Condition TMDL Scenarios:

3. *Low flow:* Simulates the future condition of maximum allowable loads for critical low stream flow conditions during the summer season.

4 *Average Annual Flow:* Simulates the future condition of maximum allowable loads under average stream flow and average annual loading conditions.

The results of scenario 3 (dotted line), which represents the maximum allowable loads for summer low flow conditions, are shown in Figure A17 in comparison to the corresponding base-line scenario (solid line). It can be seen that under the nutrient load reduction conditions, the water quality targets for dissolved oxygen and chlorophyll *a* are satisfied at all locations in the Wicomico Creek.

The results for scenario 4 (dotted line), which represents the maximum allowable loads for average annual flow, are summarized and compared to the corresponding base-line flow (solid line) in Figure A18. Again the water quality criteria for dissolved oxygen (greater than 5 mg/l) and chlorophyll *a* (less than 50 *m*g/l) are met for the entire length of the creek.

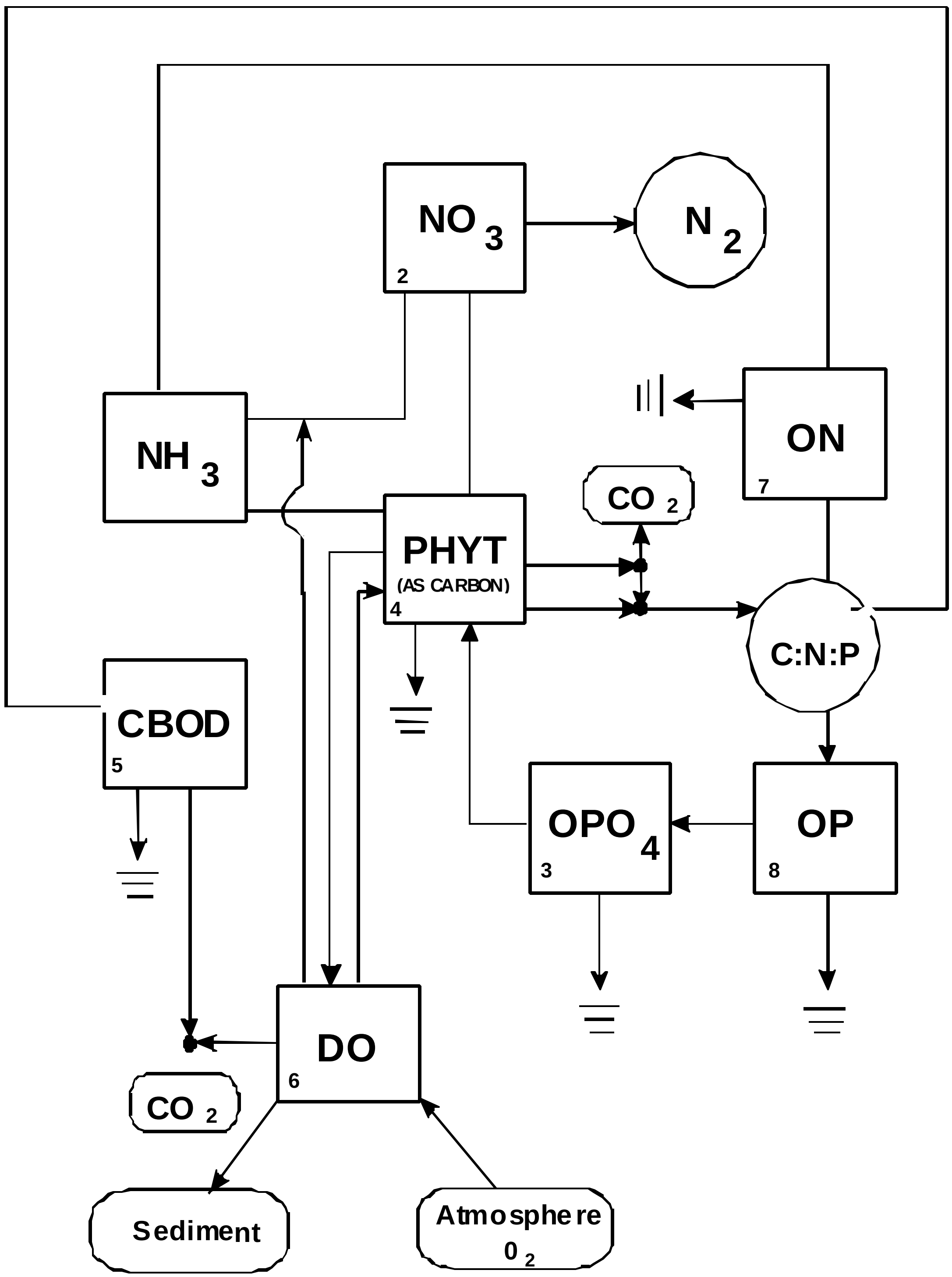


Figure A1: State Variables and Kinetic Interactions in EUTRO5.1

Table A1: Field and Laboratory Protocols

Parameter	Units	Detection Limits	Method Reference
IN SITU:			
Flow	cfs	0.01 cfs	Meter (Marsh-McBirney Model 2000 Flo-Mate)
Temperature	degrees Celsius	-5 deg. C to 50 deg. C	Linear thermistor network; Hydrolab Multiparameter Water Quality Monitoring Instruments Operating Manual (1995) Surveyor 3 or 4 (HMWQMIOM)
Dissolved Oxygen	mg/l	0 to 20 mg/l	Au/Ag polargraphic cell (Clark); HMWQMIOM
Conductivity	micro Siemens/cm (μS/cm)	0 to 100,000 μS/cm	Temperature-compensated, five electrode cell Surveyor 4; or six electrode Surveyor 3 (HMWQMIOM)
pH	pH units	0 to 14 units	Glass electrode and Ag/AgCl reference electrode pair; HMWQMIOM
Secchi Depth	meters	0.1 m	20.3 cm disk
GRAB SAMPLES:			
Ammonium	mg N / l	0.003	Chesapeake Biological Laboratory. Standard Operating Procedures. TR No. 158-97
Nitrate + Nitrite	mg N / l	0.0007	Chesapeake Biological Laboratory. Standard Operating Procedures. TR No. 158-97
Nitrite	mg N / l	0.0003	Chesapeake Biological Laboratory. Standard Operating Procedures. TR No. 158-97
Total Dissolved Nitrogen	mg N / l	0.03	Chesapeake Biological Laboratory. Standard Operating Procedures. TR No. 158-97
Particulate Nitrogen	mg N / l	0.0123	Chesapeake Biological Laboratory. Standard Operating Procedures. TR No. 158-97
Ortho-phosphate	mg P / l	0.0007	Chesapeake Biological Laboratory. Standard Operating Procedures. TR No. 158-97
Total Dissolved Phosphorus	mg P / l	0.0015	Chesapeake Biological Laboratory. Standard Operating Procedures. TR No. 158-97
Total Phosphorus	mg P / l		Chesapeake Biological Laboratory. Standard Operating Procedures. TR No. 158-97
Particulate Phosphorus	mg P / l	0.0024	Chesapeake Biological Laboratory. Standard Operating Procedures. TR No. 158-97
Dissolved Organic Carbon	mg C / l	0.15	Chesapeake Biological Laboratory. Standard Operating Procedures. TR No. 158-97
Particulate Carbon	mg C / l	0.0759	Chesapeake Biological Laboratory. Standard Operating Procedures. TR No. 158-97
Silicate	mg Si / l	0.01	Chesapeake Biological Laboratory. Standard Operating Procedures. TR No. 158-97
Total Suspended Solids	mg / l	2.4	Chesapeake Biological Laboratory. Standard Operating Procedures. TR No. 158-97
Chlorophyll *a*	μg/L	1 mg/cu.M	Standard methods for the Examination of Water and Wastewater (15^{th} ed.) #1002G. Chlorophyll. Pp 950-954
BOD_5	mg/l	0.01 mg/l	Oxidation ** EPA No. 405

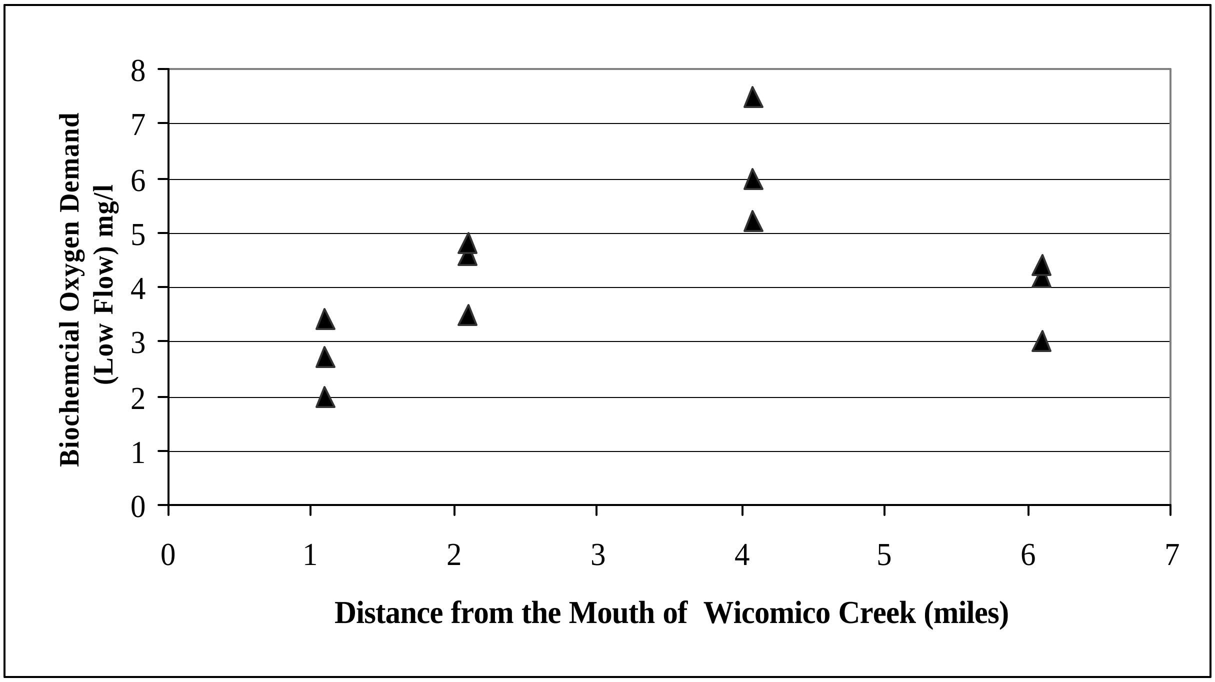


Figure A2: Longitudinal Profile of BOD Data

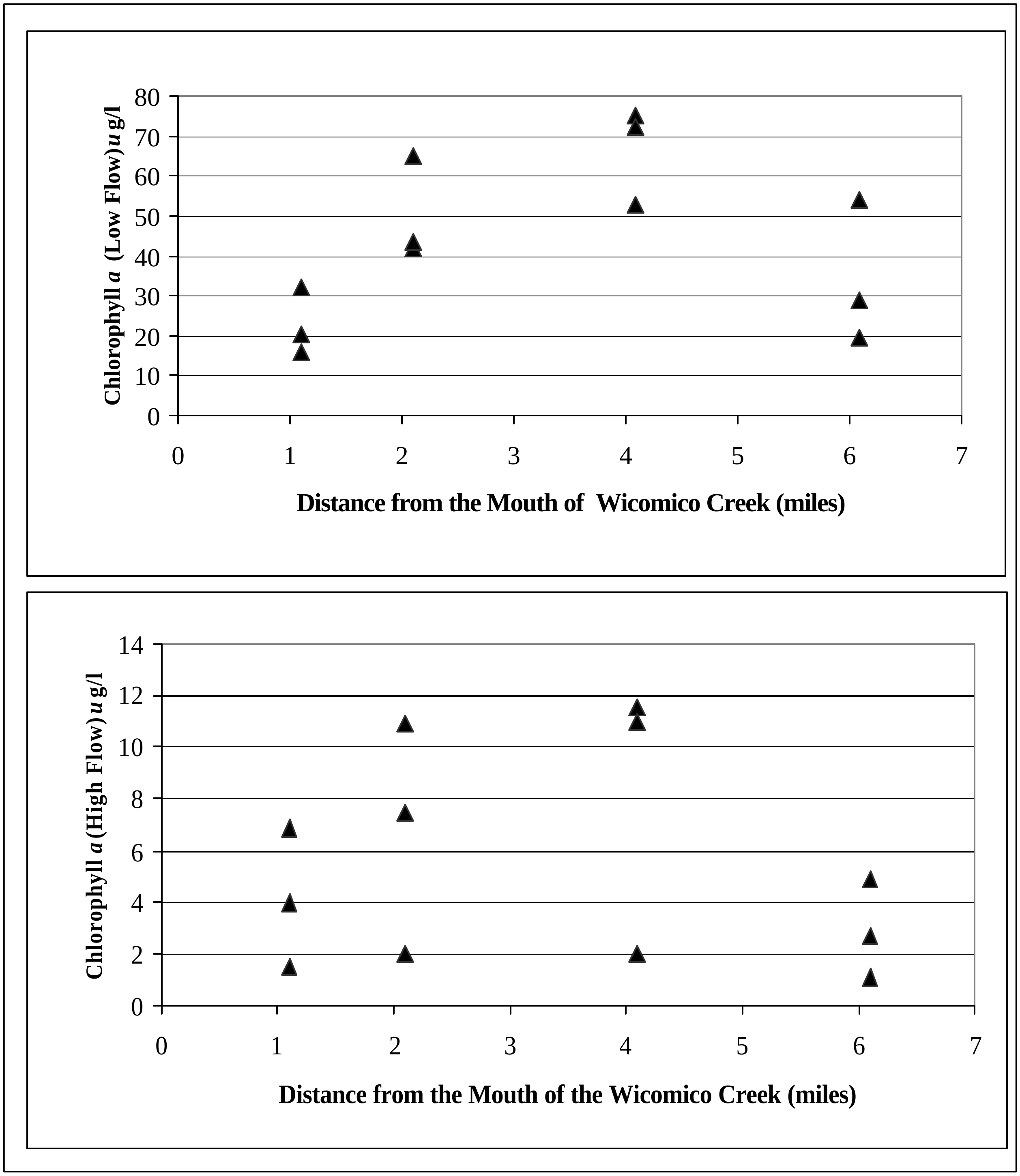


Figure A3: Longitudinal Profile of Chlorophyll *a* Data

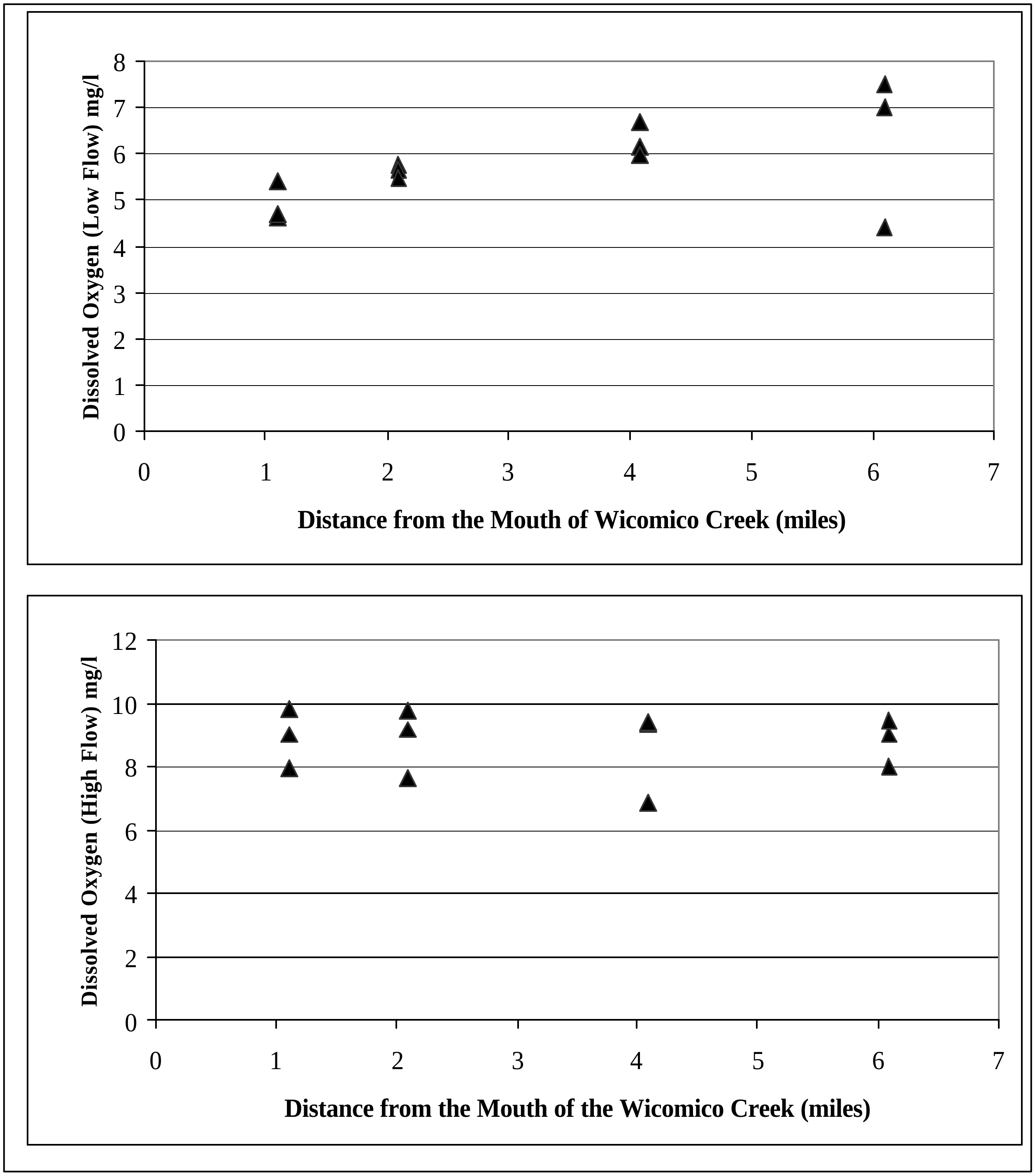


Figure A4: Longitudinal Profile of Dissolved Oxygen Data

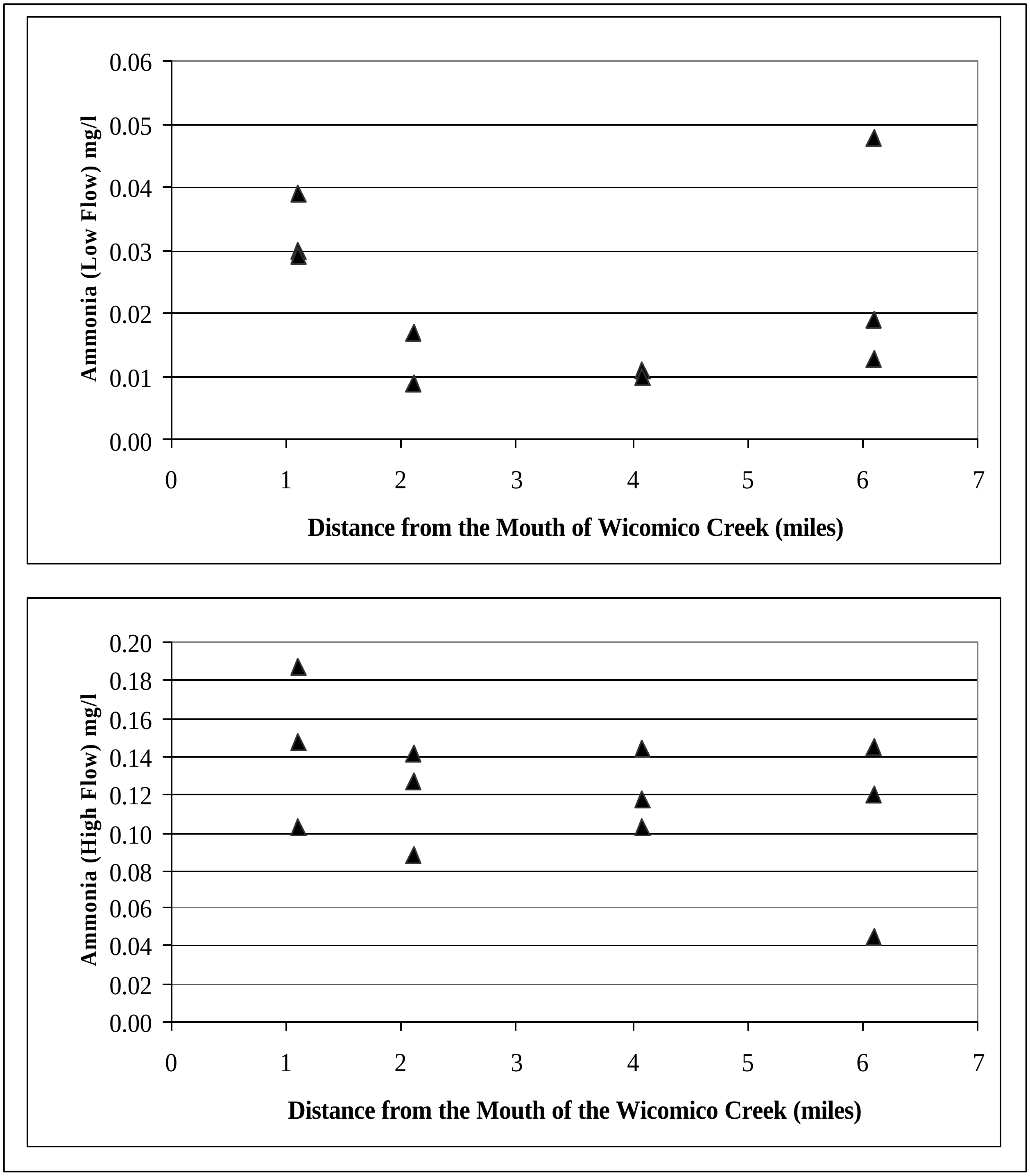


Figure A5: Longitudinal Profile of Ammonia Data

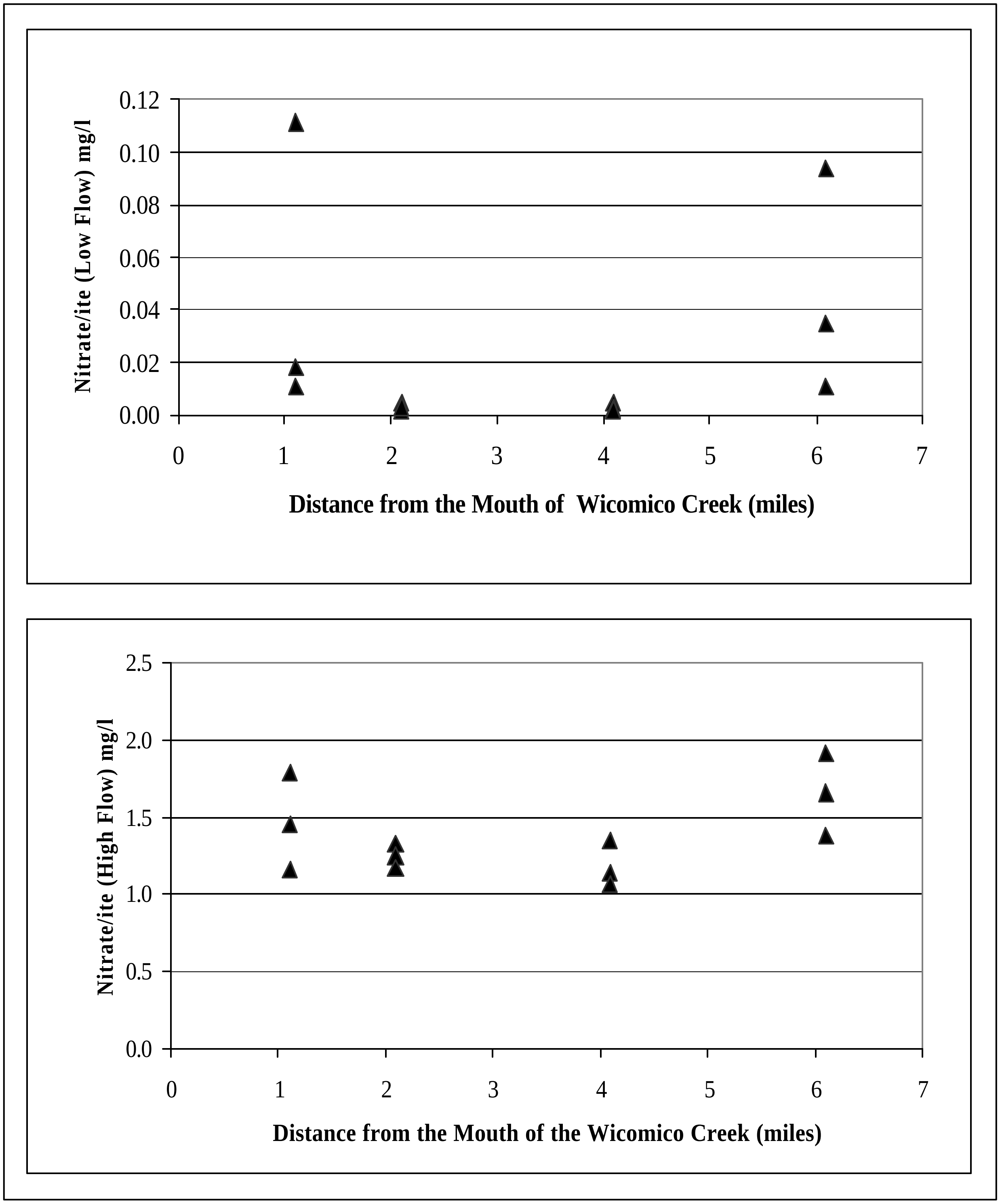


Figure A6: Longitudinal Profile of Nitrate/ite Date

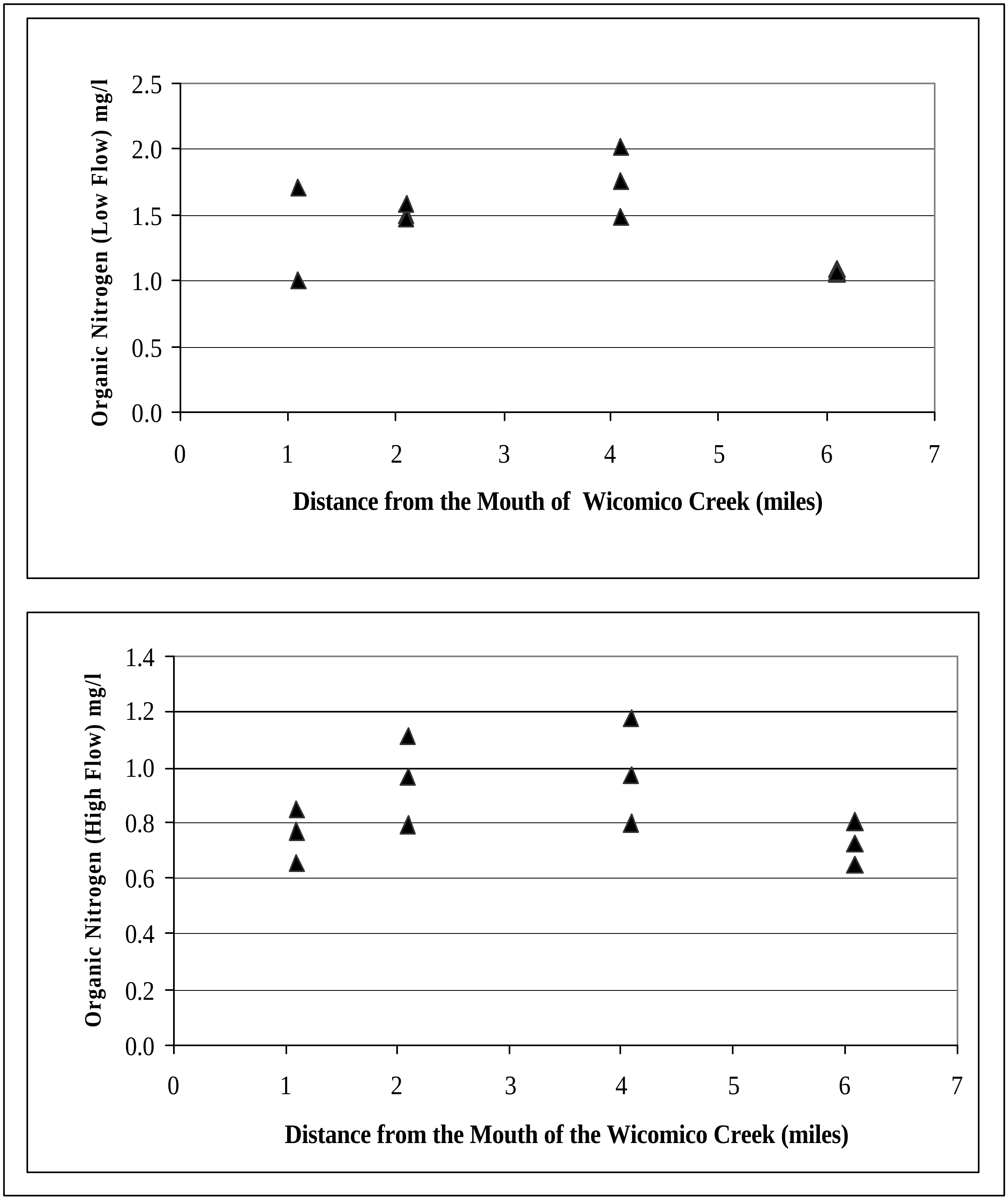


Figure A7: Longitudinal Profile of Organic Nitrogen

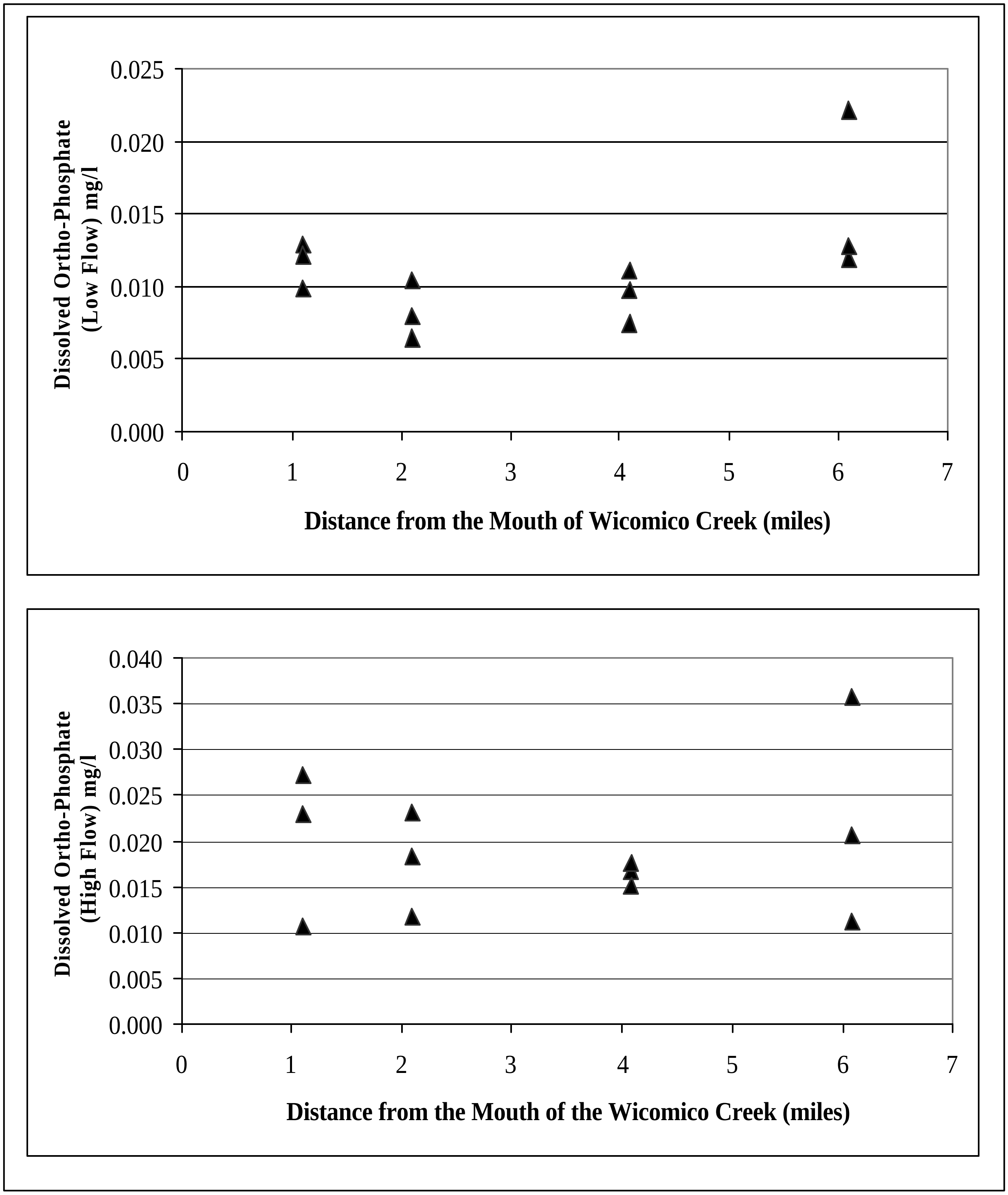


Figure A8: Longitudinal Profile of Dissolved Ortho-Phosphate

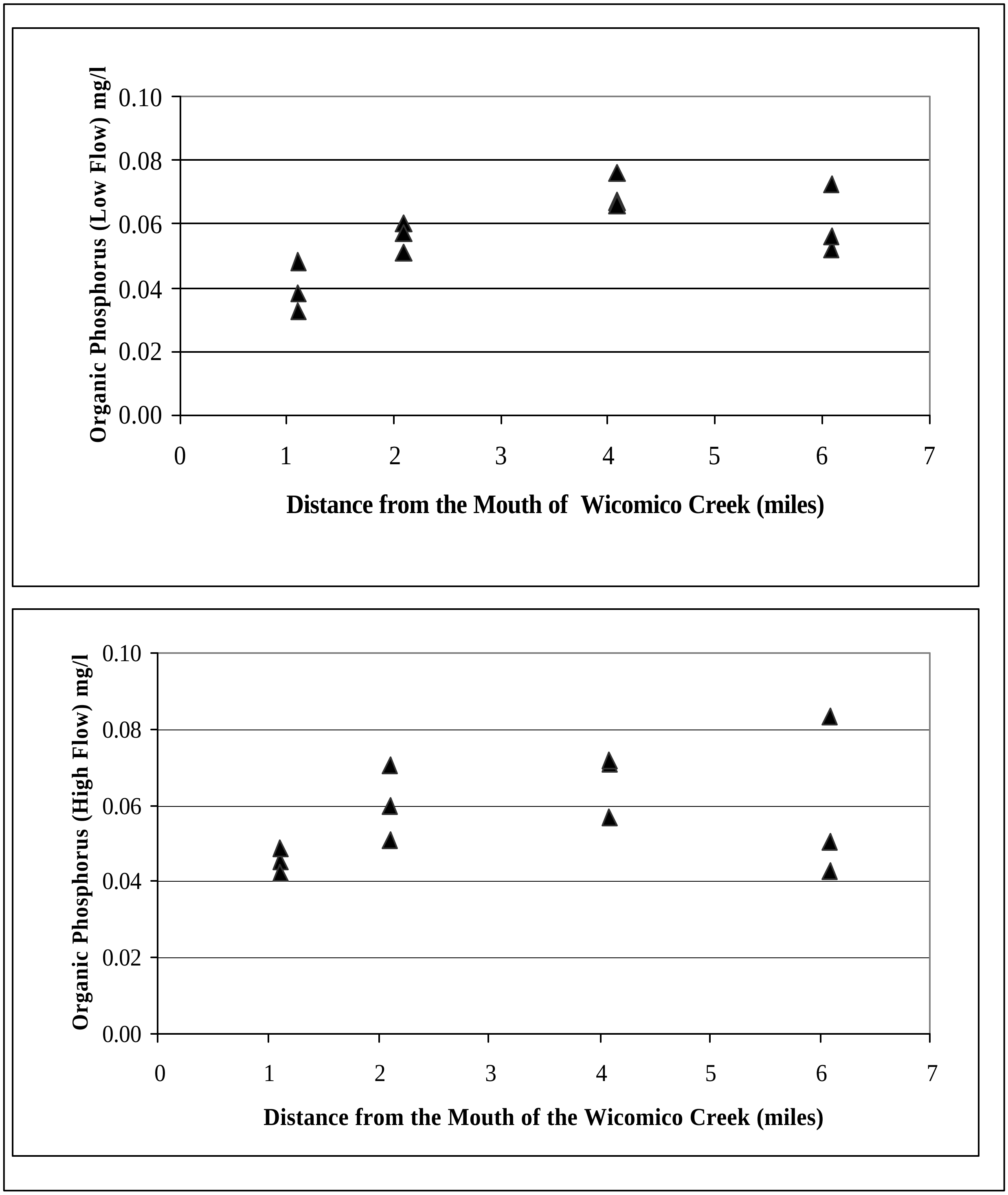


Figure A9: Longitudinal Profile of Organic Phosphorus

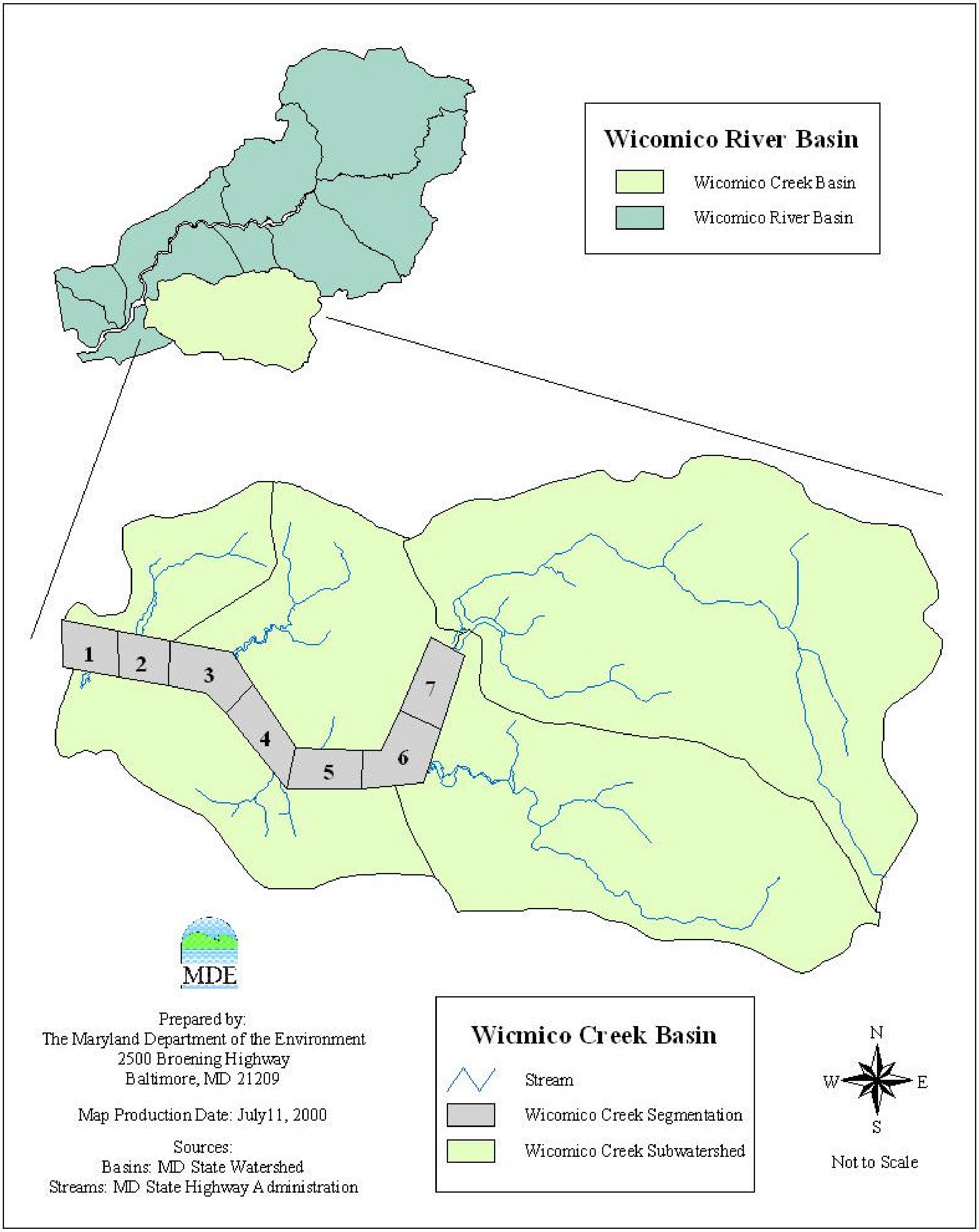


Figure A10: Model Segmentation and Subwatersheds

Table A2: Volumes, Characteristic Lengths, and Interfacial Areas Used in the WCEM

Segment Pair	Volume (m^3)	Characteristic Length (m)	Interfacial Area (m^2)
1	1294140	877	589
2	1163706	1612	1077
3	462301	1601	317
4	382064	1589	256
5	300686	1608	191
6	205555	1636	128
7	110833	1594	61

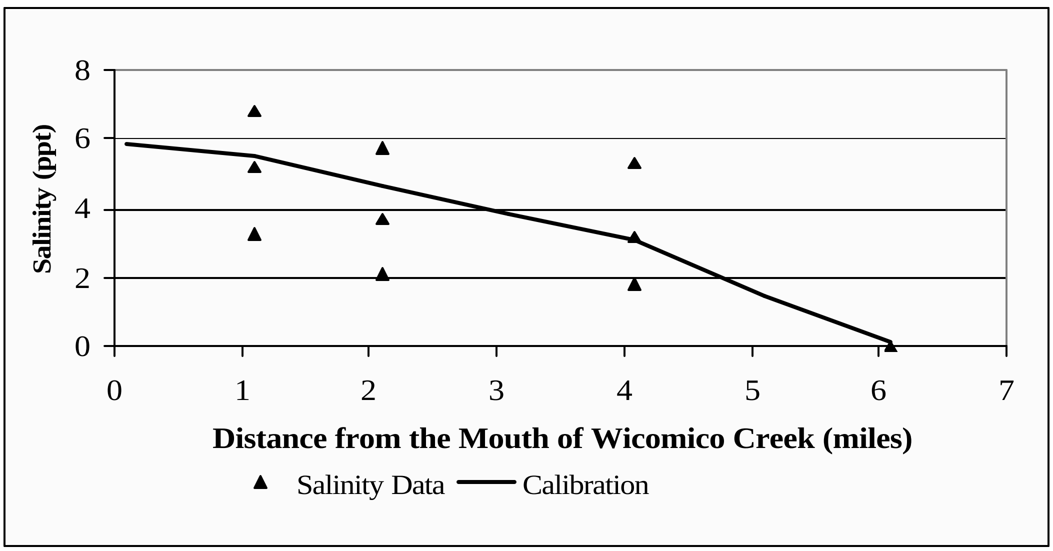


Figure A11: Results of the Calibration of Exchange Coefficients for Low Flow

Table A3: Dispersion Coefficients used in the WCEM

Exchange Pair	Dispersion Coefficient (m^2/sec)
0 - 1	2.70
1 - 2	2.70
2 - 3	2.70
3 - 4	2.70
4 - 5	2.70
5 - 6	0.90
6 - 7	0.15
7 - 0	0.01

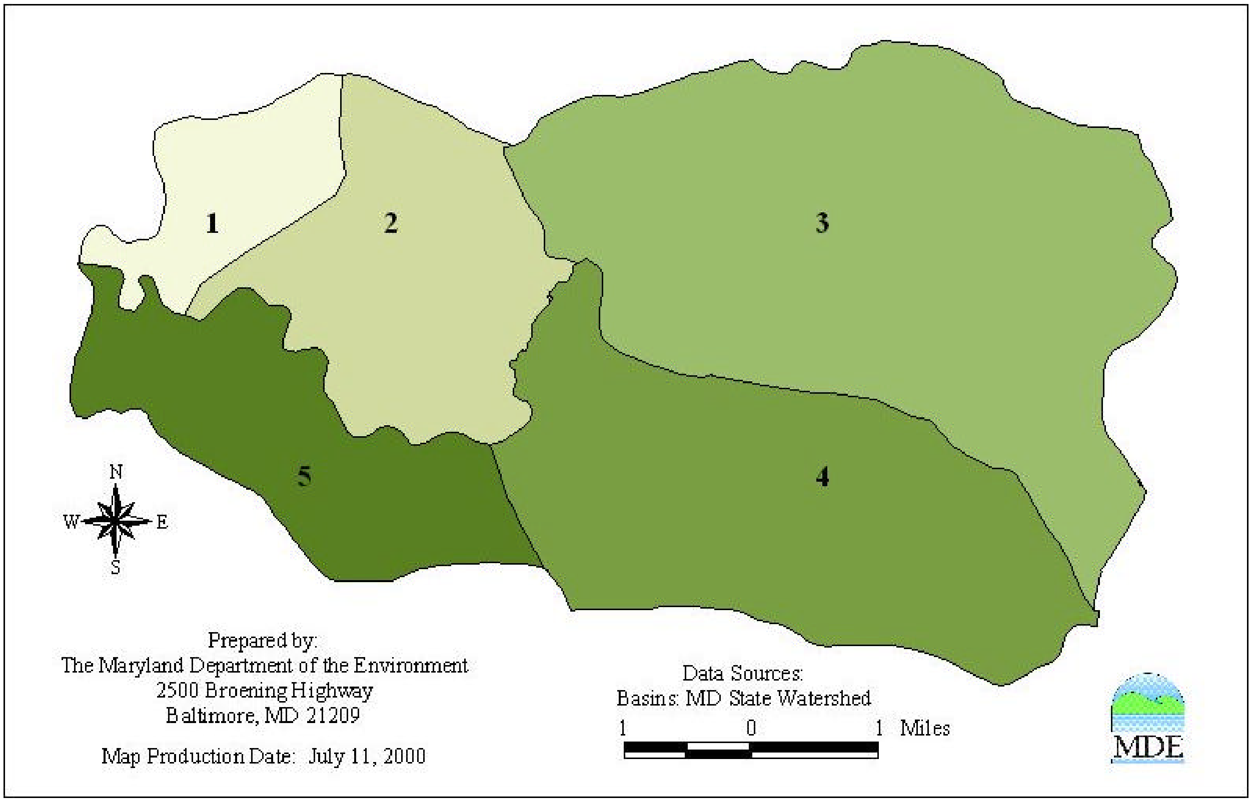


Figure A12: The Five Subwatersheds of the Wicomico Creek Drainage Basin

Table A4: Subwatershed Flow for Low, High, and Average Conditions

Subwatershed	Area (km^2)	Low Flow (m^3/sec)	High Flow (m^3/sec)	Average Flow (m^3/sec)
1	4.9	0.007	0.211	0.054
2	12.0	0.010	0.522	0.133
3	32.6	0.046	1.416	0.362
4	31.3	0.038	1.361	0.348

Table A5: Solar Radiation, Photoperiod, and Temperature Used in the Calibration of the WCEM

Segment	Solar Radiation (langleys)		Photoperiod (day)		T (^{0}C)	
	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
1	450	300	.55	.50	11.8	26.9
2	450	300	.55	.50	11.8	24.8
3	450	300	.55	.50	11.8	24.8
4	450	300	.55	.50	11.8	24.8
5	450	300	.55	.50	11.8	24.8
6	450	300	.55	.50	11.8	24.8
7	450	300	.55	.50	11.8	26.3

Table A6: Extinction Coefficients, Salinity, Sediment Oxygen Demand, and Nutrient Fluxes Used in the Calibration of the WCEM

Segment	K_e (m^{-1})		Salinity (g/L)		SOD (g O_2/m^2 day)		FNH_4 (mg NH_4-N/m^2 day)		FPO_4 (mg PO_4-P/m^2 day)	
	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
1	3.5	3.5	0.670	5.20	2.4	2.4	35.0	35.0	0.8	0.8
2	4.0	4.0	0.001	5.05	2.0	2.0	30.0	30.0	0.7	0.7
3	4.0	4.0	0.001	3.93	1.7	1.7	25.0	25.0	0.7	0.7
4	5.2	5.2	0.001	3.76	1.1	1.1	20.0	20.0	0.6	0.6
5	5.2	5.2	0.001	3.60	0.9	0.9	10.0	10.0	0.5	0.5
6	6.0	6.0	0.001	1.80	0.9	0.9	10.0	10.0	0.5	0.5
7	6.0	6.0	0.000	0.00	0.5	0.5	10.0	10.0	0.0	0.0

Table A7: EUTRO5.1 Kinetic Coefficients

Constant	Code	Value
Nitrification rate	K12C	0.10 *day* -1 at 20^o C
temperature coefficient	K12T	1.08
Denitrification rate	K20C	0.08 *day* -1 at 20^o C
temperature coefficient	K20T	1.08
Saturated growth rate of phytoplankton	K1C	2.0 *day* -1 at 20^o C
temperature coefficient	K1T	1.08
Endogenous respiration rate	K1RC	0.035 *day*-1 at 20^o C
temperature coefficient	K1RT	1.045
Nonpredatory phytoplankton death rate	K1D	0.055*day* -1
Phytophankton Stoichometry		
Oxygen-to-carbon ratio	ORCB	2.67 $mg\ O_2 / mg\ C$
Carbon-to-chlorophyll ratio	CCHL	45
Nitrogen-to-carbon ratio	NCRB	0.25 *mg N/mg C*
Phosphorus-to-carbon ratio	PCRB	0.025 $mg\ PO_4\text{-}P/ mg\ C$
Half-saturation constants for phytoplankton growth		
Nitrogen	KMNG1	0.01 *mg* N / L
Phosphorus	KMPG1	0.004 *mg* P / P
Phytoplankton	KMPHY	0.0 *mg* C/ *L*
Grazing rate on phytoplankton	K1G	0.0 *L / cell-day*
Fraction of dead phytoplankton recycled to organic		
nitrogen	FON	0.5
phosphorus	FOP	0.5
Light Formulation Switch	LGHTS	1 = Smith
Saturation light intensity for phytoplankton	IS1	300. *Ly/day*
BOD deoxygenation rate	KDC	0.03 *day* -1 at 20^o C
temperature coefficient	KDT	1.05
Half saturation const. for carb. deoxygenation	KBOD	0.0
Reaeration rate constant	k2	0.11 *day* -1 at 20^o C
Mineralization rate of dissolved organic nitrogen	K71C	0.01 *day*-1
temperature coefficient	K71T	1.08
Mineralization rate of dissolved organic phosphorus	K58C	0.05 *day* -1
temperature coefficient	K58T	1.08
Phytoplankton settling velocity		0.0086 *m/day*
Organics settling velocity		0.0086 *m/day*

Table A8: Flows and Subwatershed Contributions to the Model Segments for Low Flow

Segment	Subwatershed Contribution	Area (km^2)	Low Flow (m^3/sec)
2	1 (100%) + 4 (0%)	7.138	0.0069
3	2 (15%) + 4 (0%)	6.950	0.0069
4	2 (0%) + 4 (8%)	4.633	0.0036
5	2 (20%) + 4 (11%)	5.976	0.0085
6	2(0%) + 4 (67%)	22.424	0.0297
7	2 (0%) + 3 (100%)	33.663	0.0465

Table A9: Flows and Subwatershed Contributions to the Model Segments for High and Average Flow

Segment	Subwatershed Contribution	Area (km^2)	High Flow (m^3/sec)	Average Flow (m^3/sec)
2	1 (100%) + 4 (7%)	7.138	0.310	0.0793
3	2 (40%) + 4 (7%)	6.950	0.302	0.0772
4	2 (18%) + 4 (8%)	4.633	0.201	0.0515
5	2 (20%) + 4 (11%)	5.976	0.260	0.0664
6	2(13%) + 4 (67%)	22.424	0.974	0.2491
7	2 (9%) + 3 (100%)	33.663	1.462	0.3740

Table A10: Nonpoint Source Concentrations for the Calibration of the Model for Low Flow

Segment	NH_4 (mg/l)	NO_{23} (mg/l)	PO_4 (mg/l)	*CHL* a (μg/l)	*CBOD* (mg/l)	DO (mg/l)	ON (mg/l)	OP (mg/l)
1	0.036	0.090	0.025	18.401	3.444	4.965	1.127	0.049
2	0.040	1.851	0.020	14.340	5.111	7.537	0.687	0.034
3	0.040	1.851	0.020	14.340	5.111	7.537	0.687	0.034
4	0.040	1.851	0.020	14.340	5.111	7.537	0.687	0.034
5	0.040	1.851	0.020	14.340	5.111	7.537	0.687	0.034
6	0.040	1.851	0.020	14.340	5.111	7.537	0.687	0.034
7	0.027	0.046	0.034	34.057	6.444	6.300	1.071	0.078

Table A11: Nonpoint Source Concentrations for the Calibration for High Flow

Segment	NH_4 (mg/l)	NO_{23} (mg/l)	PO_4 (mg/l)	CHL *a* (mg/l)	CBOD (mg/l)	DO (mg/l)	ON (mg/l)	OP (mg/l)
1	0.252	1.722	0.043	3.323	3.333	9.210	0.827	0.077
2	0.042	1.901	0.021	2.854	3.333	8.633	0.961	0.020
3	0.042	1.901	0.021	2.854	3.333	8.633	0.961	0.020
4	0.042	1.901	0.021	2.854	3.333	8.633	0.961	0.020
5	0.042	1.901	0.021	2.854	3.333	8.633	0.961	0.020
6	0.042	1.901	0.021	2.854	3.333	8.633	0.961	0.020
7	0.103	1.650	0.039	2.883	3.333	8.833	0.726	0.075

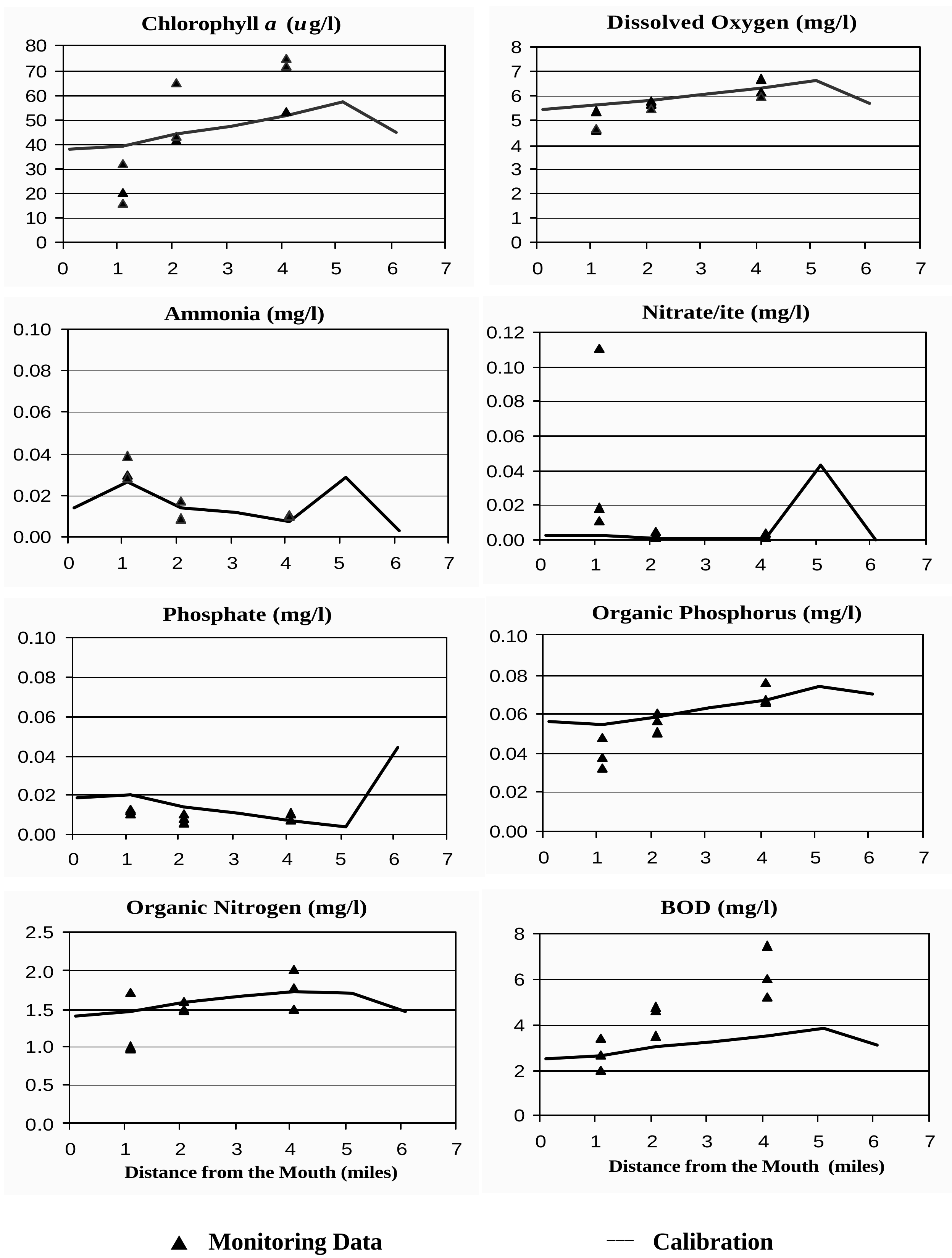
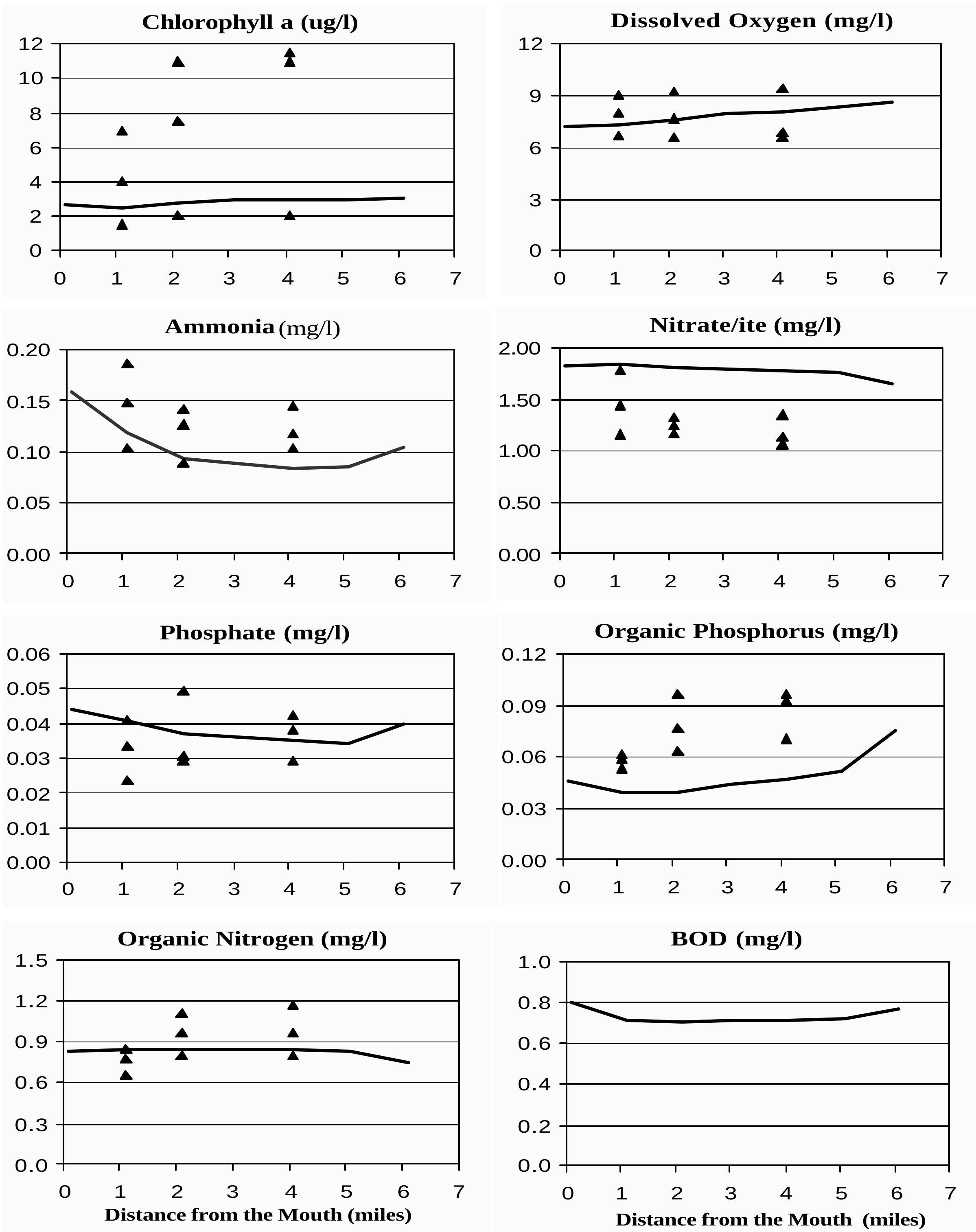


Figure A13: Low Flow Calibration of the Wicomico Creek



▲ Monitoring Data **— Calibration**

Figure A14: High Flow Calibration of the Wicomico Creek

Table A12: Nonpoint Source Concentrations for the Base-line Low Flow Condition (Scenario 1)

Segment	NH_4 (mg/l)	NO_{23} (mg/l)	PO_4 (mg/l)	CHL *a* (mg/l)	CBOD (mg/l)	DO (mg/l)	ON (mg/l)	OP (mg/l)
1	0.036	0.090	0.025	18.401	3.444	4.965	1.127	0.049
2	0.040	1.851	0.020	14.340	5.111	7.537	0.687	0.034
3	0.040	1.851	0.020	14.340	5.111	7.537	0.687	0.034
4	0.040	1.851	0.020	14.340	5.111	7.537	0.687	0.034
5	0.040	1.851	0.020	14.340	5.111	7.537	0.687	0.034
6	0.040	1.851	0.020	14.340	5.111	7.537	0.687	0.034
7	0.027	0.046	0.034	34.057	6.444	6.300	1.071	0.078

Table A13: Nonpoint Source Concentrations for the Base-line Average Flow Condition (Scenario 2)

Segment	NH_4 (mg/l)	NO_{23} (mg/l)	PO_4 (mg/l)	CHL *a* (mg/l)	CBOD (mg/l)	DO (mg/l)	ON (mg/l)	OP (mg/l)
1	0.144	0.906	0.034	10.862	3.333	6.894	0.977	0.063
2	0.164	1.322	0.077	8.597	3.333	8.085	0.859	0.091
3	0.170	1.487	0.087	8.597	3.333	8.085	0.862	0.100
4	0.167	1.486	0.082	8.597	3.333	8.085	0.821	0.095
5	0.148	1.324	0.073	8.597	3.333	8.085	0.753	0.084
6	0.122	1.098	0.052	8.597	3.333	8.085	0.755	0.065
7	0.173	1.291	0.072	20.697	3.333	7.386	1.124	0.093

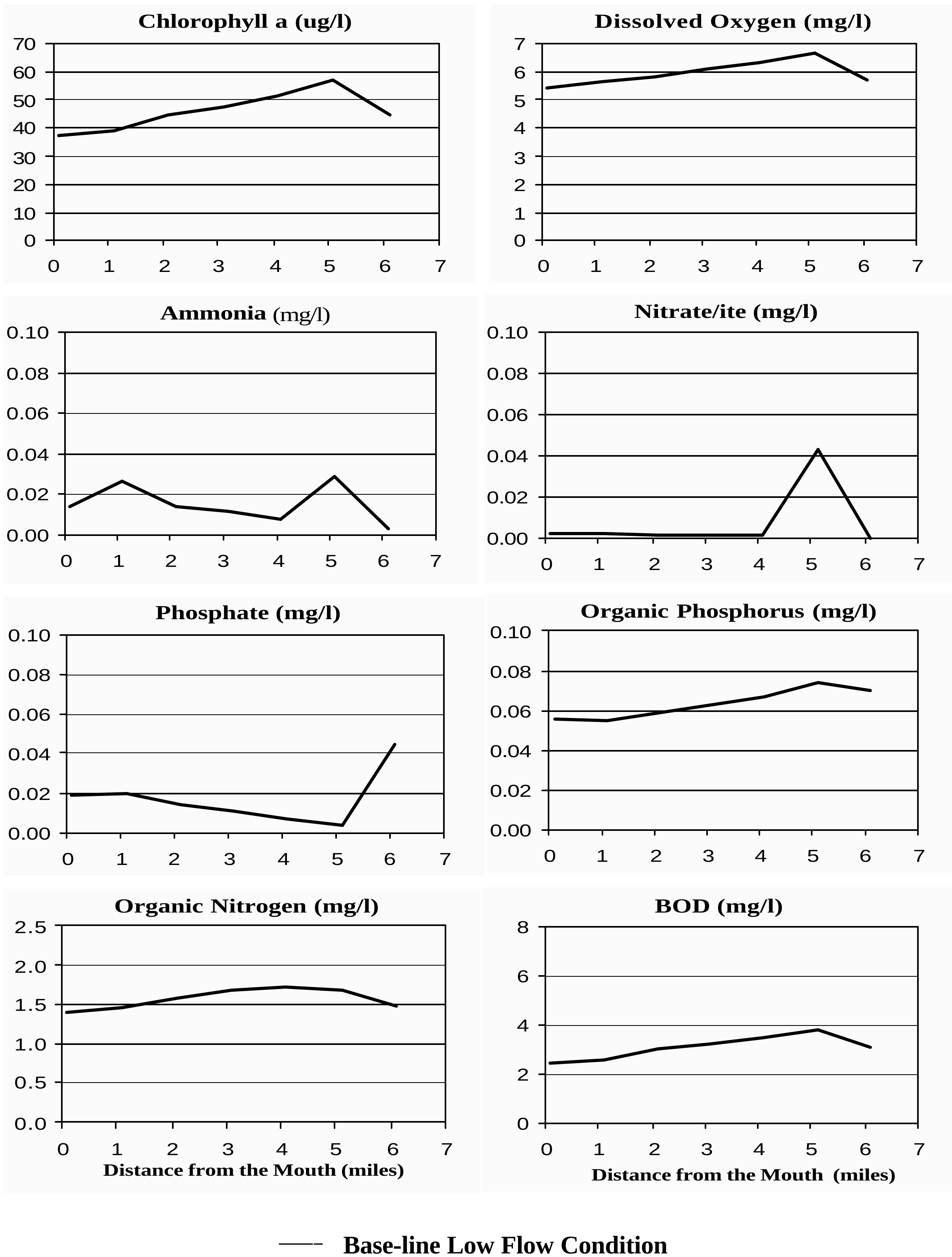
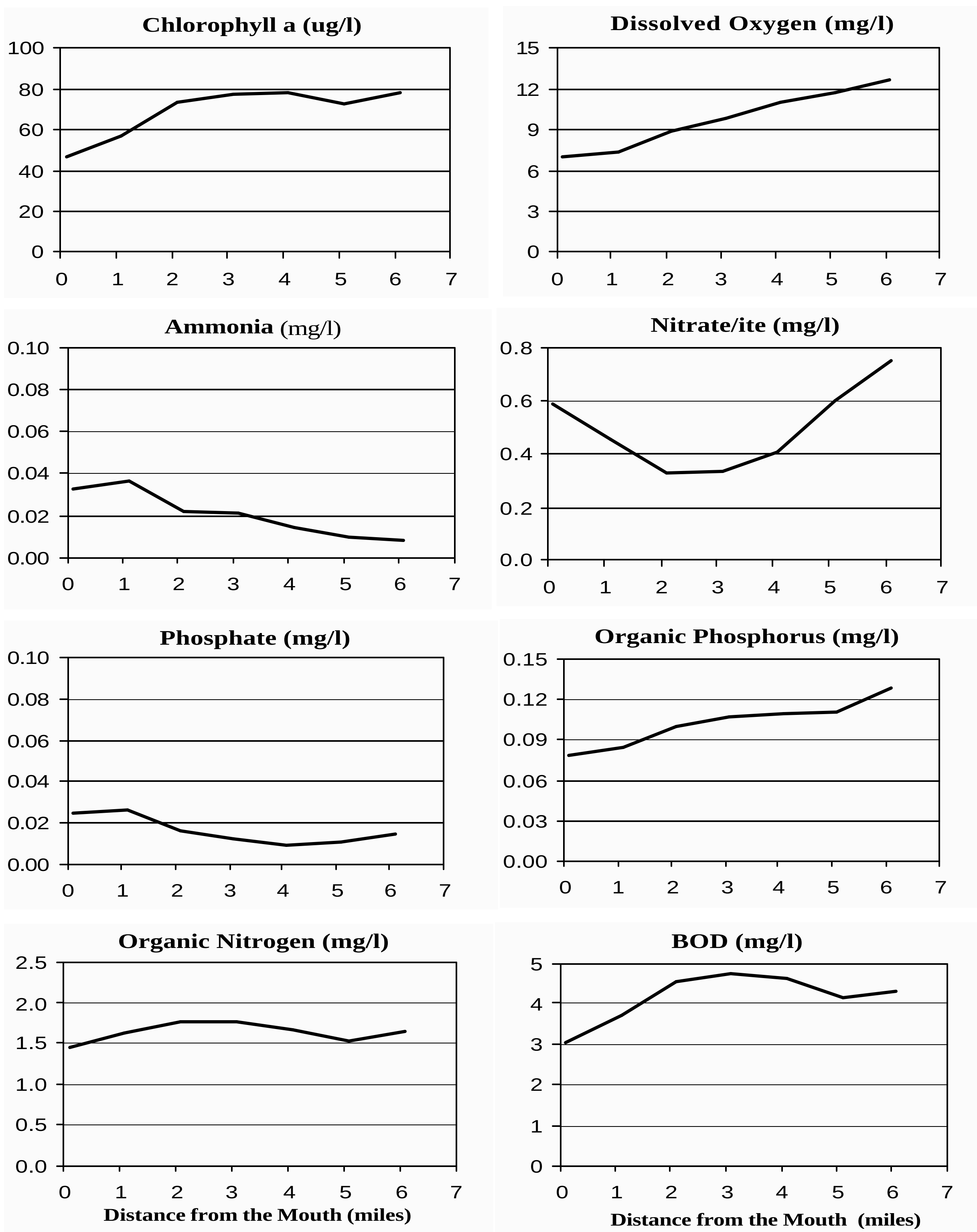
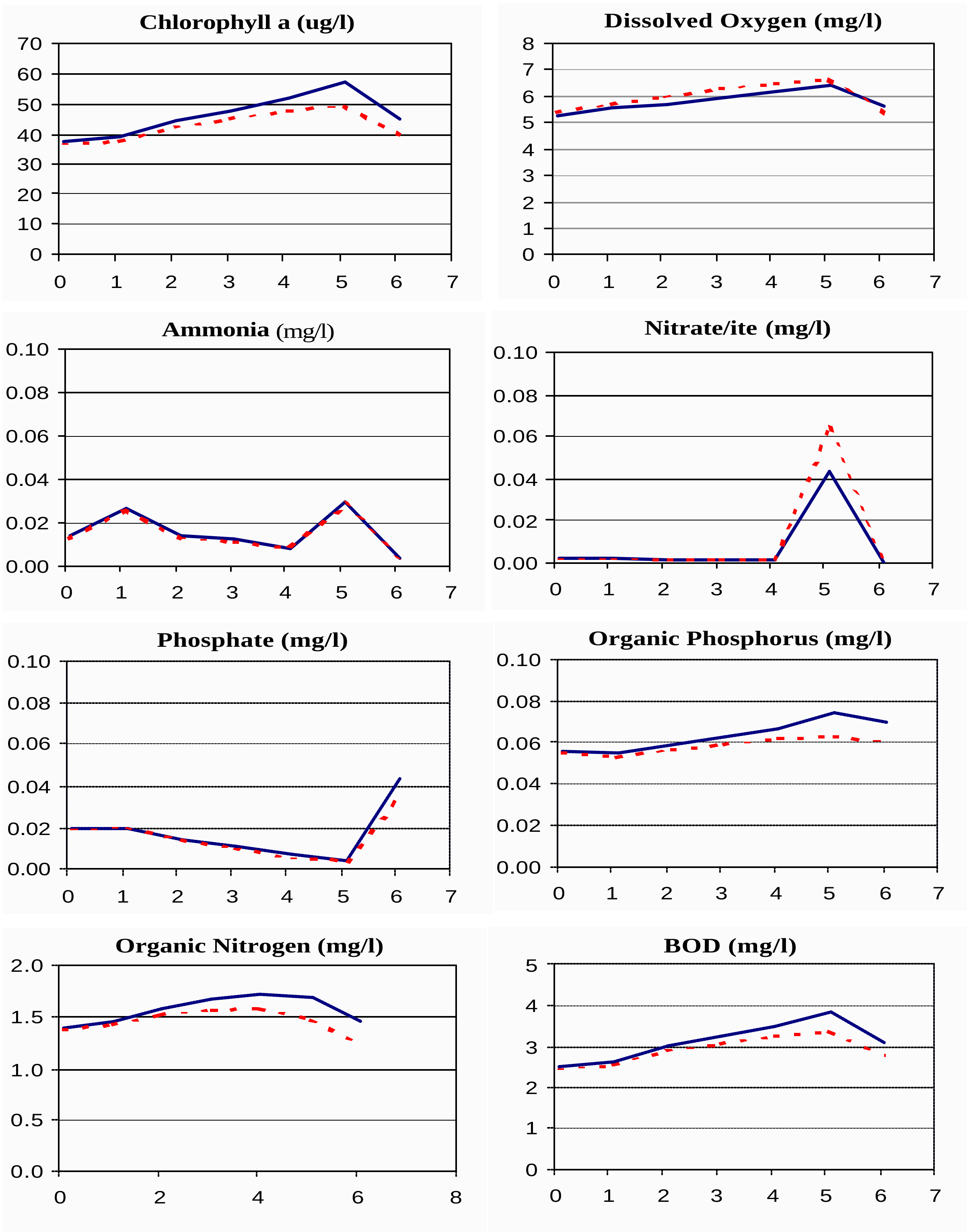


Figure A15: Base-line Low Flow Scenario of the Wicomico Creek



Base-line Average Flow Condition

Figure A16: Base-line Average Flow Scenario of the Wicomico Creek



Base-line Low Flow Condition ---- **Future Low Flow TMDL Condition**

Figure A17: Future Low Flow Scenario Results of the Wicomico Creek

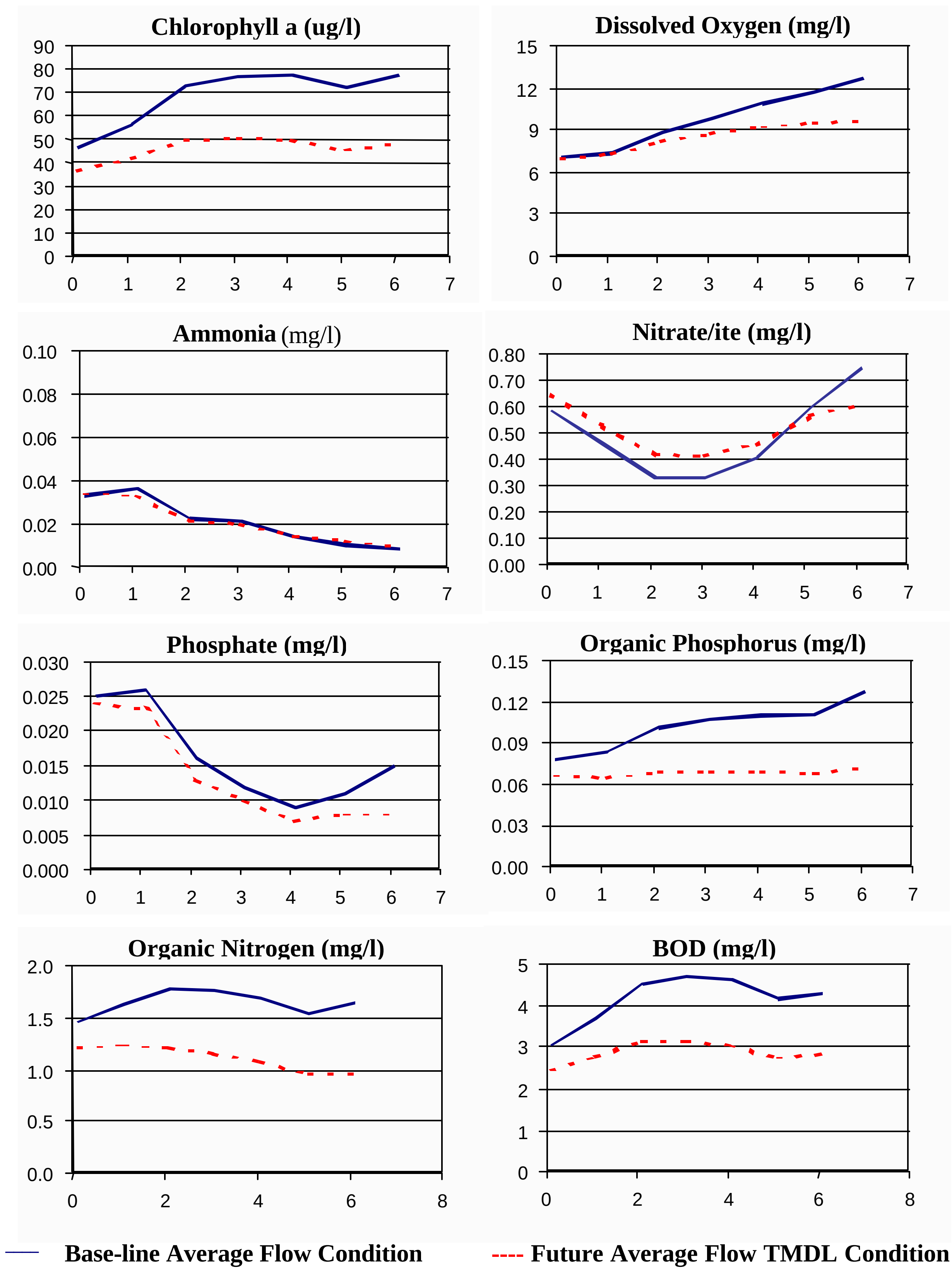


Figure A18: Future Average Flow Scenario Results of the Wicomico Creek

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