Report Version: January 16, 2001

APPENDIX A

Total Maximum Daily Loads of
Nitrogen and Phosphorus for
the Bohemia River
Cecil County, Maryland

Appendix A

MODELING FRAMEWORK

The computational framework chosen for the modeling of water quality in the Bohemia River 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 researches, 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 March 24, April 20, May 18, July 27, August 25, and September 28, 1999. 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 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 March, April, and May data were used to calibrate the high flow water quality model whereas July, August, and September data were used to calibrate the low flow water quality model for the Bohemia River. Figures A2 – A6 present low flow and high flow water quality profiles along the river.

INPUT REQUIREMENTS [1]

Model Segmentation and Geometry

The spatial domain of the Bohemia River Eutrophication Model (BREM) extends from the confluence of the Bohemia River and the Big Elk River for about 10 miles up the mainstem of the Bohemia River. Following a review of the bathymetry for Bohemia River, the model was divided into 11 water quality segments. Figure A7 shows the model segmentation for the development of BREM. Table A2 lists the volumes, characteristic lengths and interfacial areas of the 11 segments.

Dispersion Coefficients

The dispersion coefficients were calibrated using the WASP5.1 model and in-stream water quality data from 1999. The WASP5.1 model was set up to model 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 the salinity from the water at the tidal boundary at the mouth. For the model execution, salinities at all boundaries except the tidal boundary were set to zero. Flows were obtained from a nearby USGS gage regression as explained in more detail below. Figure A8 shows the results of the calibration of the dispersion coefficients for low flow. The same sets of dispersion coefficients were used for both high flow and low flow calibration, because of insufficient salinity data for a reasonable high flow salinity calibration. Final values of the dispersion coefficients are listed in Table A3.

Freshwater Flows

Freshwater flows were calculated after the Bohemia drainage basin was delineated into 8 subwatersheds (Figure A9). These subwatersheds closely correspond with the Maryland Department of Natural Resources 12-digit basin codes. As necessary, the subwatersheds were refined to assure they were consistent with the 11 water quality segments developed for the BREM. The BREM was calibrated for two sets of flow conditions: high flow and low flow. The high flow corresponds to the months of March, April and May, while the low flow corresponds to the months of July, August and September.

The flow for each subwatershed was estimated based on four nearby USGS stations: USGS gage #01495800 (Long C Nr Chesapeake City, MD), USGS gage #01495000 (Big Elk C At Elk Mills, MD), USGS gage #01495500 (L Elk C At Childs, MD), USGS gage #01494500 (Jacobs C Nr Sassafras, MD). An average flow for each individual station was determined by obtaining an average value over three high flow months (March, April, and May) for the entire range of the flow data available. A ratio of flow to drainage area was calculated for each of the USGS station

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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 river 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 |

and then an average of all the four flow to area ratios was determined. The high flow for each subwatershed was then determined by multiplying the average flow to area ratio as calculated above by the watershed area. The low flows used in the model for different subwatersheds were determined in the similar manner by averaging the stations over summer months (July, August and September) and then following procedure described above for high flow. The 7Q10 flow for the individual subwatersheds was also determined in a similar manner by obtaining the 7Q10 flow for the individual USGS stations and then following above procedure. Table A4 presents flows from different subwatersheds during high, low, and 7Q10 flow conditions.

For high flow, each sub-watershed was assumed to contribute a flow to the Bohemia mainstem. Based on observations in the field, the following assumptions were made about low flow; there was 100% of the relative USGS regression flow coming from the mainstem, there was 50% of the relative USGS flow coming from the subwatersheds which have streams to carry the flow to the mainstem, and there was no flow from the other subwatersheds. These flows and loads were assumed to be direct inputs to the BREM.

Point and Nonpoint Source Loadings

There is one minor point source, Cecilton WWTP, (0.05 mgd municipal wastewater treatment plant) contributing load to the Bohemia River. This source falls outside the modeling domain and causes a minor localized DO problem in one minor tributary called Black Duck Creek. This issue will be dealt at a later date. However, the loads from the WWTP are included in the BREM as part of the load entering segment 5. Nonpoint source loadings were estimated for both low flow and high flow conditions. Loads for the low flow conditions were estimated as the product of observed low flow concentrations and estimated flows as described above. Being observed loads, they account for all sources. Similarly, high flow loads were obtained as the product of high flow concentrations and estimated high flows.

Nonpoint source loads for the calibration of the model were calculated using data from two water quality stations one within the Bohemia River Basin and the other at the confluence with the Big Elk River. Data from station XJI9438 was used as a boundary condition for segment 1 of the BREM. The boundary conditions for the remaining non-tidal boundaries were based on data from station LBO0036. This is the only free flowing station in the watershed and it was assumed to be a reasonable representation of background water quality in the watershed. BOD data was not available for high flow, and was assumed to be 2.0 mg/l at all boundaries.

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 (NO23), 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 Bohemia River. They are 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) (Table A5).

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)

Nonliving organic nutrient components settle from the water column into the sediment at an estimated settling rate velocity of 0.06 *m/day*, and phytoplankton was estimated to settle through the water column at a rate of 0.01 *m/day*. In general, it is reasonable to assume that 50% of the nonliving organics are in the particulate form. Such assignments were borne out through model sensitivity analyses and were within the range of literature value.

Different SOD values were estimated for different BREM reaches based on observed environmental conditions and literature values (Thomann, 1987). The highest SOD values were assumed to occur in the lower reaches of the river. High concentrations of nutrients and chlorophyll *a*, which had a high potential to settle out due to slower stream velocity, were observed in these reaches. A maximum SOD value of 1.0 $gm\ O_2/m^2 day$ was used.

Kinetic Coefficients

The water column kinetic coefficients are universal constants used in the BREM model. They are formulated to characterize the kinetic interactions among the water quality constituents. The initial values were taken from past modeling studies of Potomac River (Clark and Roesh, 1978; Thomann and Fitzpatrick, 1982; Cerco, 1985), and of Mattawoman Creek (Haire and Panday, 1985, Panday and Haire, 1986, Domotor *et al*., 1987), and the Patuxent River (Lung, 1993). The kinetic coefficients are listed in Table A6.

Initial Conditions

The initial conditions used in the model were chosen to reflect the observed values as closely as possible. However, because the model simulation was run for a long period of time before it reached equilibrium, it was found that initial conditions did not impact the final results.

CALIBRATION & SENSITIVITY ANALYSIS

The EUTRO5.1 model for low flow was calibrated with July, August and September 1999 data. Tables A7, A8 & A10 show the nonpoint source flows and loads associated with the calibration input file (segment 5 combines the nonpoint source load with the load from the Cecilton WWTP). Tables A9 and A11 show the point source flows and concentrations from Cecilton WWTP and the nonpoint source loads from Black Duck Creek separately. Figures A10 – A17 show the results of the calibration of the model for low flow. As can be seen, in Figure A11 the model did a good job of capturing the trend in the dissolved oxygen data. The model did capture the peak chlorophyll *a*, and BOD concentrations and also the general trend (Figure A10, A12) although it was not able to capture the lower concentrations very well near the mouth of the river. The model did a good job of capturing the trends of nitrate plus nitrite concentrations, organic nitrogen, and organic phosphorus (Figure A13, A14 and A16) It was also able to replicate the ammonia and the ortho-phosphate trends although it did not capture the middle range of values very well (Figure A15, and A17).

The EUTRO5.1 model for high flow was calibrated with March, April and February 1999 data. The results are presented in Figures A18 to A25. As can be seen the model did well in capturing almost all the state variables, except the chlorophyll *a* and BOD concentration, suggesting that the model is not capable of simulating higher chlorophyll *a* concentration in winter compared to summer as the simulations are guided by the temperature of the system.

SYSTEM RESPONSE

The EUTRO5.1 model of Bohemia River was applied to several different low stream flow conditions to project the impacts of nutrients on algal production (as chlorophyll *a*) and low dissolved oxygen. The model was not used to predict high flow conditions because of its inability to predict algal blooms seen during cold temperatures with its present formulation. In addition, outstanding questions remain concerning whether or not cold weather algal production represents a water quality problem. The Maryland Department of Environment will consider these conditions at a later date

Model Run Descriptions

The first scenario represents the expected conditions of the stream under current loading conditions during critical low flow (7Q10 flow condition). The 7Q10 low flow for each subwatershed was estimated using the same method described above to estimate low flow using four nearby USGS gages. The total nonpoint source loads were computed as the product of observed 1999 base-flow concentrations and the estimated 7Q10 low flow. Because the loads are based on observed concentrations, they account for all background and human-induced sources. The loads from the WWTP are included as part of the load entering segment 5. The point source load reflects approved water and sewer plan maximum flows and estimated future maximum concentrations at the WWTP. All the environmental parameters used for scenario 1 remained the same as for the low flow calibration of the model. The nonpoint source loads for model scenario 1 can be seen in Table A12.

A number of iterative model scenarios involving nutrient reductions were explored to determine the maximum allowable loads. The second scenario shows the water quality response in the river for the maximum allowable loads for the critical low flow. To estimate feasible nitrogen and phosphorus nonpoint source reductions, the percent of the load that is controllable was estimated for each subwatershed based on the land uses. It was assumed that all of the loads from cropland, feedlots, and urban 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, because loads from specific land uses were not available for low flow.

For the 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 an initial estimate was made of the total organic nitrogen and organic phosphorus settling to the river bottom, from particulate nutrient organics, living algae, and phaeophytin, in each segment. This was done by running the base-line scenario once with estimated settling of organics and chlorophyll *a*, then again with no settling. The difference in the organic matter between the two runs was assumed to settle to the river 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 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 expected 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 new fluxes were calculated. The process was repeated several times, 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 $gm\ O_2/m^2\ day$.

The second scenario represents improved conditions associated with the maximum allowable loads to the stream during critical low flow. The flow was the same as scenario one. A margin of safety of 5% was included in the load calculation. The nitrogen and phosphorus loads were reduced from scenario 1 (base line) to meet the chlorophyll *a* goal of 50 $\mu g/l$, and the dissolved oxygen criterion of no less than 5.0mg/l. The loads from the WWTP are included as part of the load entering segment 5. The point source load reflects approved water and sewer plan maximum flows and estimated future maximum concentrations. More information about point source loads can be found in the Technical Memorandum entitled “Significant Nutrient Point Sources in the Bohemia River Watershed.” All the environmental parameters (except nutrient fluxes and SOD) and kinetic coefficients used for the calibration of the model remained the same as scenario 1.

Scenario Results

Base-line Loading Condition Scenarios:

Low Flow: Simulates critical low stream flow (7Q10) conditions during summer season. Water quality parameters (e.g., nutrient concentrations) are based on 1999 observed data. The point source load assumes maximum approved water and sewer plan flow and appropriate parameter concentrations expected to occur at that flow (0.08 mgd for Cecilton WWTP).

The BREM 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, which utilize radiant energy from the sun to convert water and carbon dioxide into glucose, and release oxygen. Because the photosynthetic process is dependent on solar radiant energy, the production of oxygen proceeds only during daylight hours. 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 morning predawn hours when the algae have been without light for the longest period of time. 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 BREM based on the amount of chlorophyll *a* in the water. For the rest of the model results, the minimum dissolved oxygen concentration is reported.

The first scenario represents the expected summer low flow conditions when water quality is impaired by high chlorophyll *a* levels, and low dissolved oxygen concentrations. The results for scenario 1 can be seen in Figures A26-A33. The peak chlorophyll *a* levels are seen above the desired goal of 50 µg/l, but the dissolved oxygen levels are within the water quality standard of 5 mg/l.

Future Condition TMDL Scenarios:

Low Flow: Simulates the future condition of maximum allowable loads for critical low stream flow (7Q10) conditions during summer season to meet the water quality in the Bohemia River.

The results of the second scenario indicate that, under summer low flow conditions, the water quality target for dissolved oxygen and chlorophyll *a* will be satisfied at all locations along the mainstem of the Bohemia River with a non point source reduction of 31% (both N & P) or greater. The results of scenario 2 are presented in Figures A34-A41.

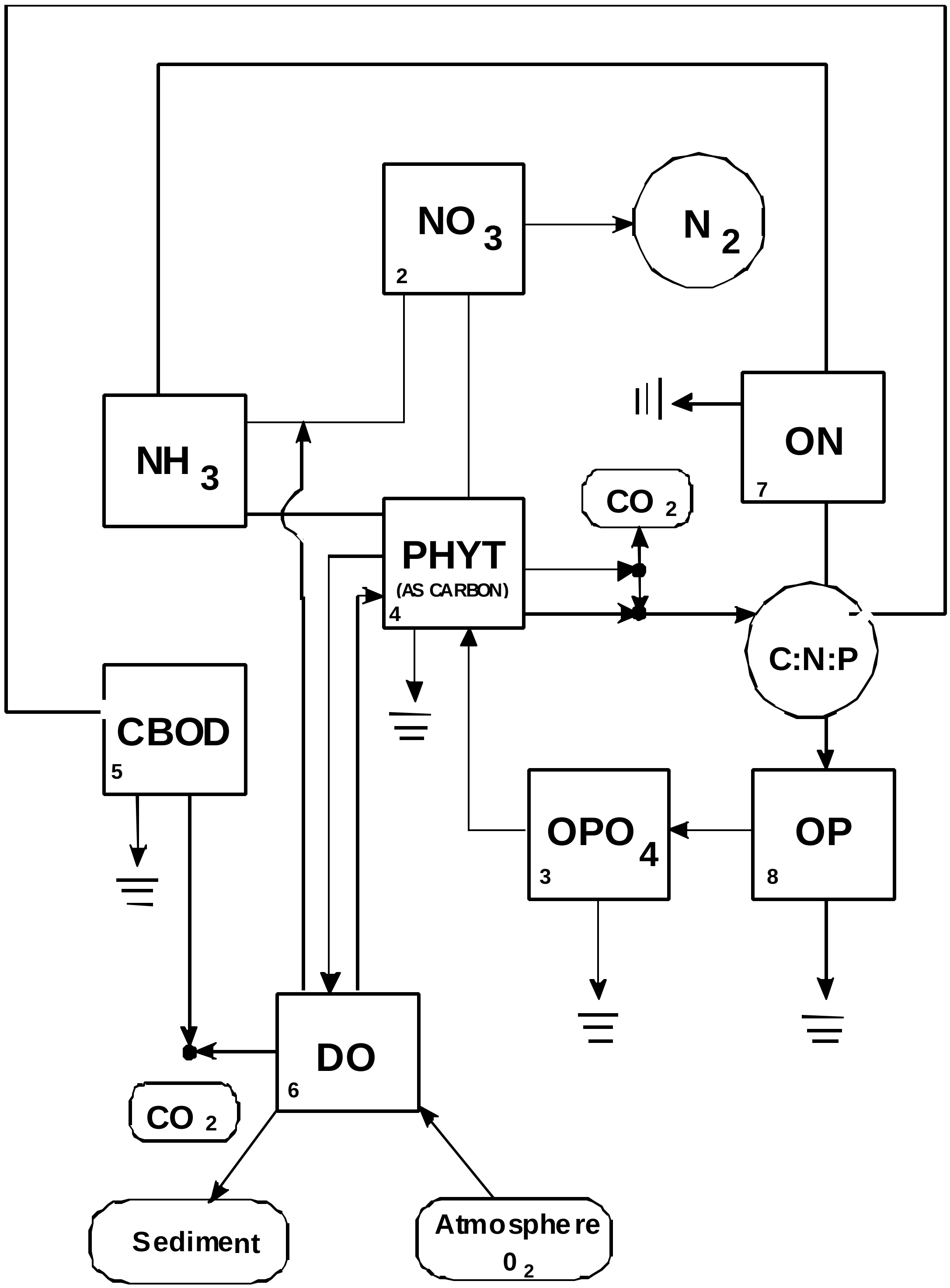

Figure A1: State Variables and Kinetic Interactions in EUTRO5

Table A1: Field and Laboratory Protocals

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

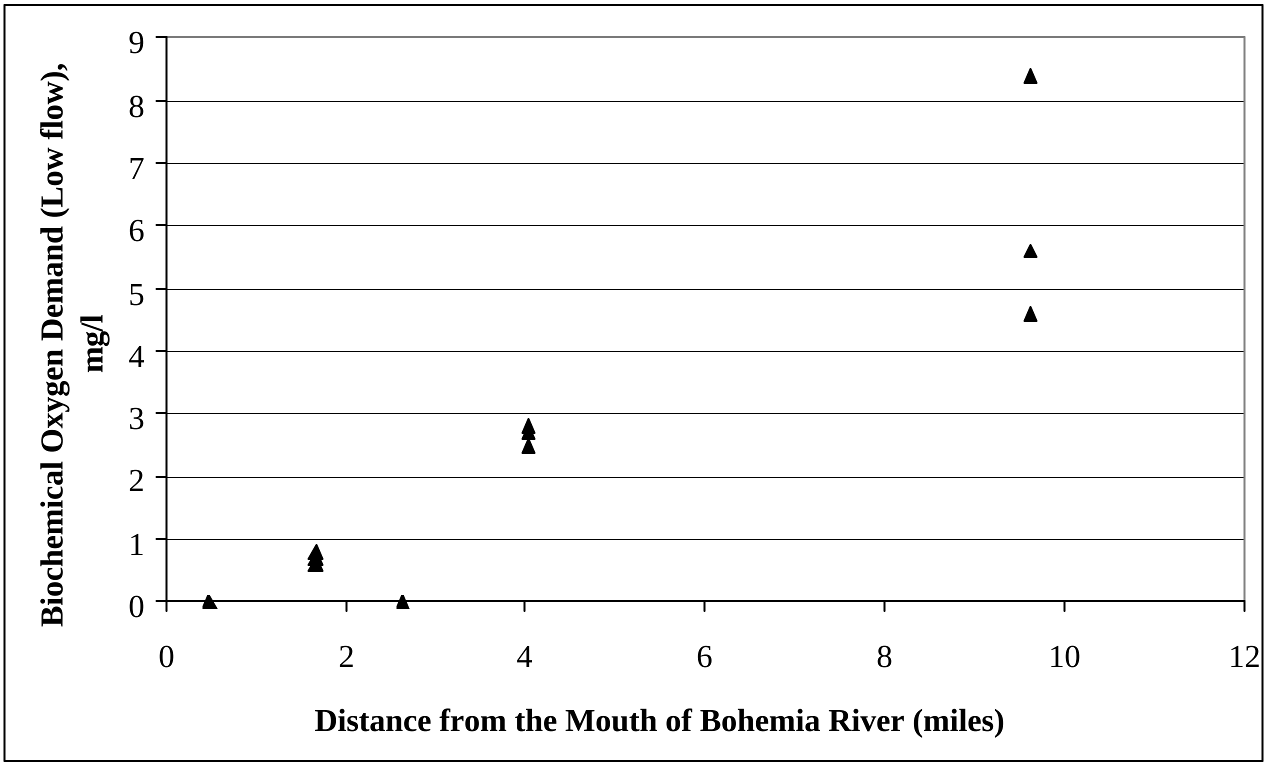

Figure A2: Longitudinal Profile of BOD Data

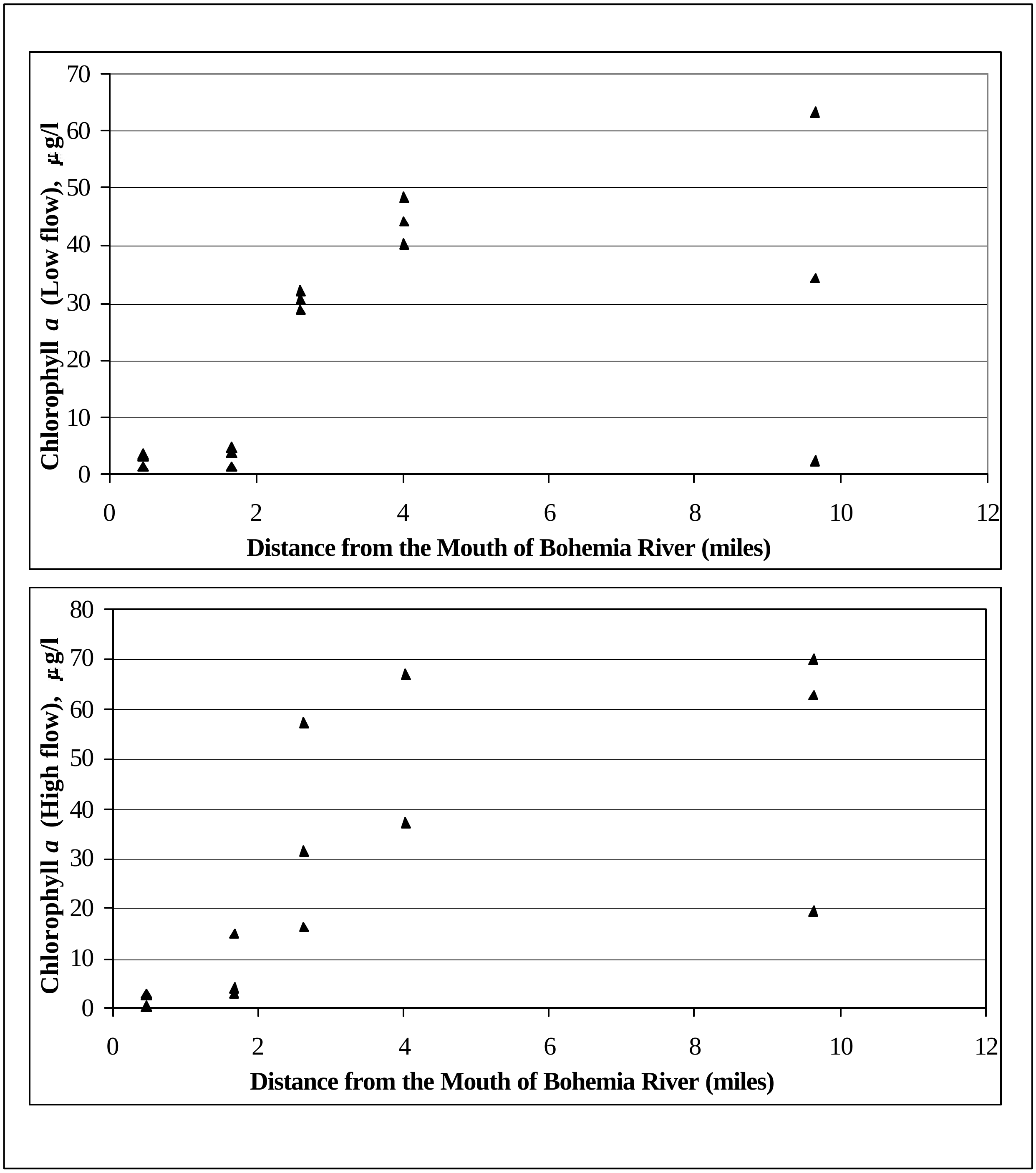

Figure A3: Longitudinal profile of Chlorophyll *a* data

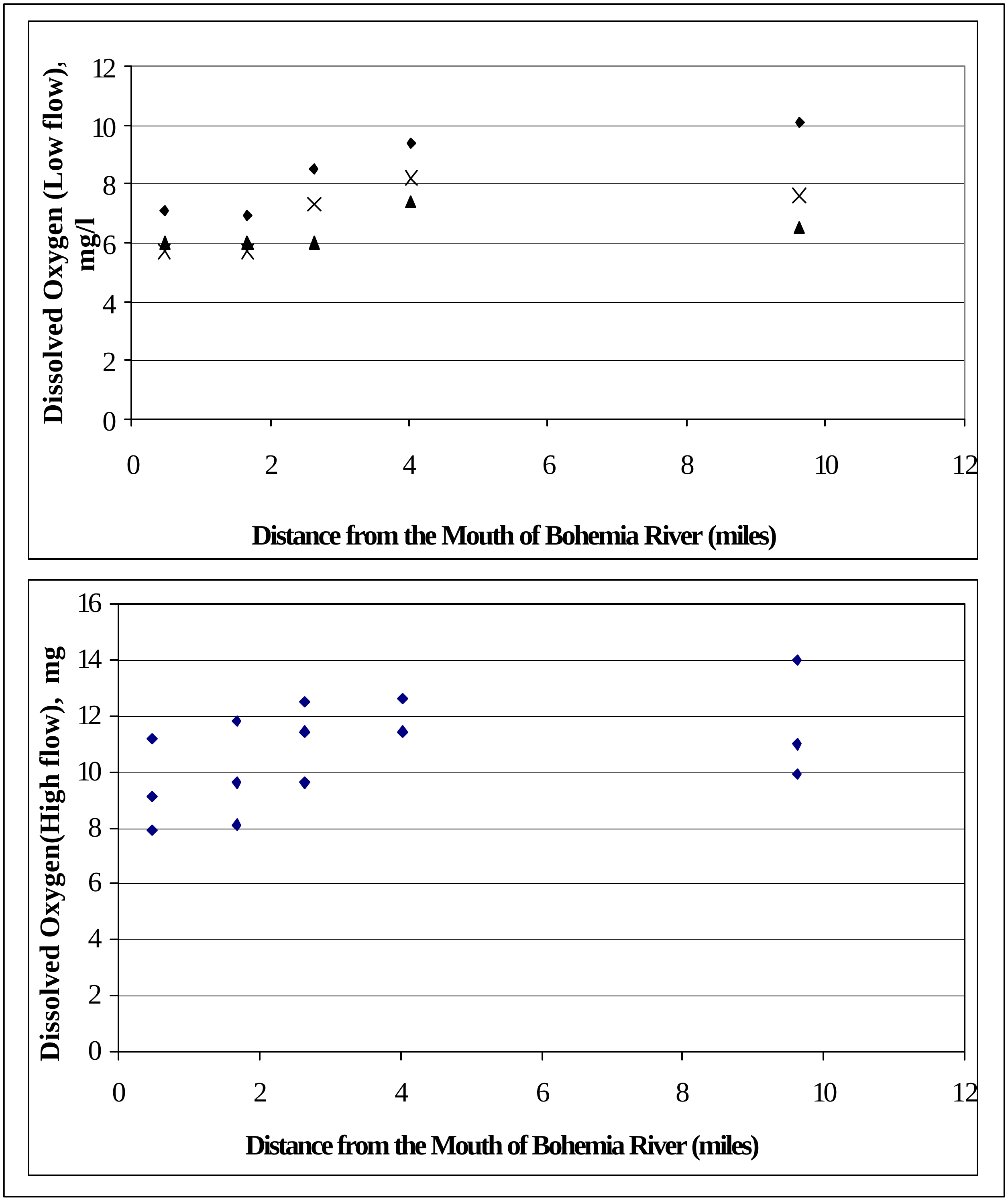

Figure A4: Longitudinal Profile of Dissolved Oxygen Data

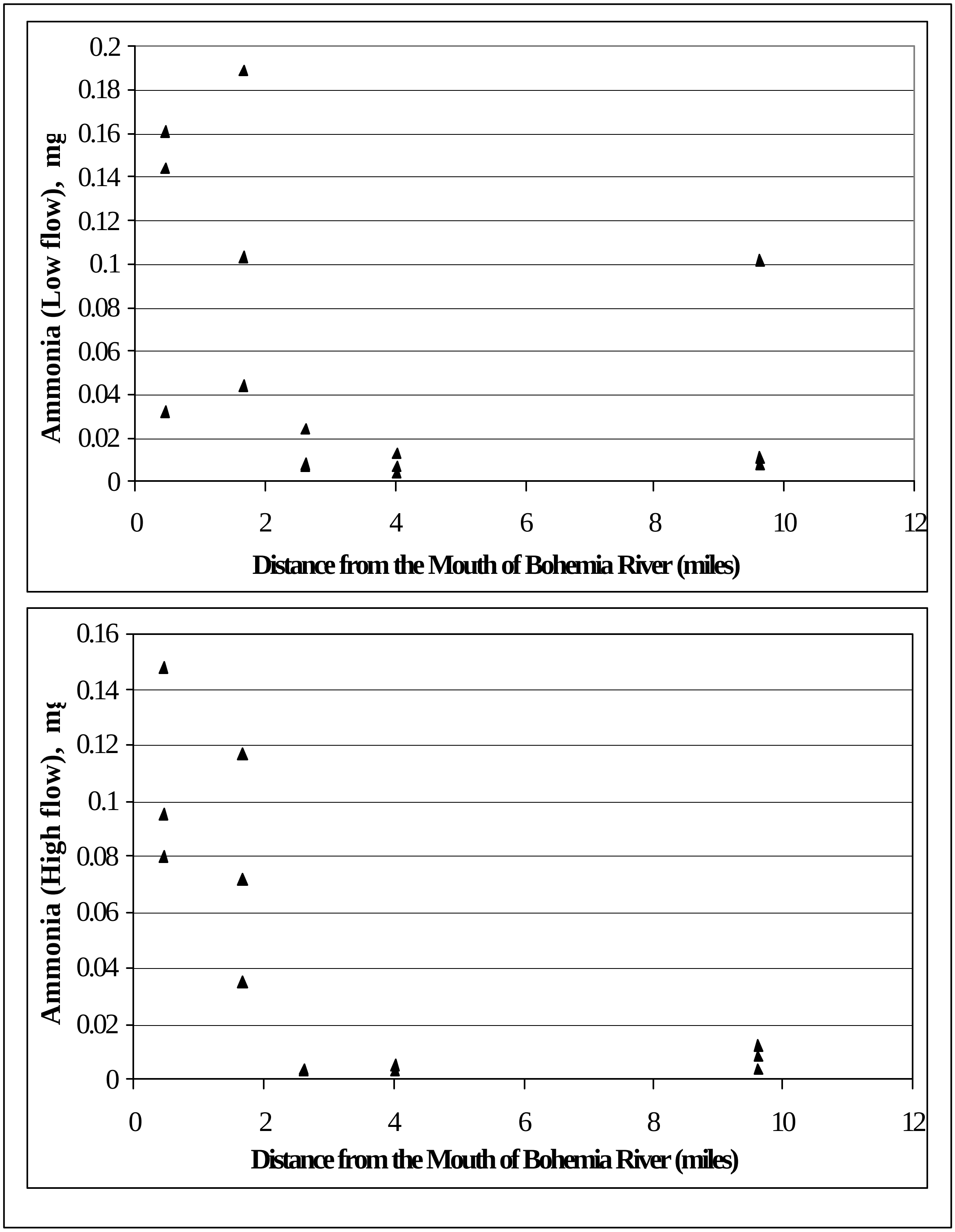

Figure A5: Longitudinal Profile of Ammonia Data

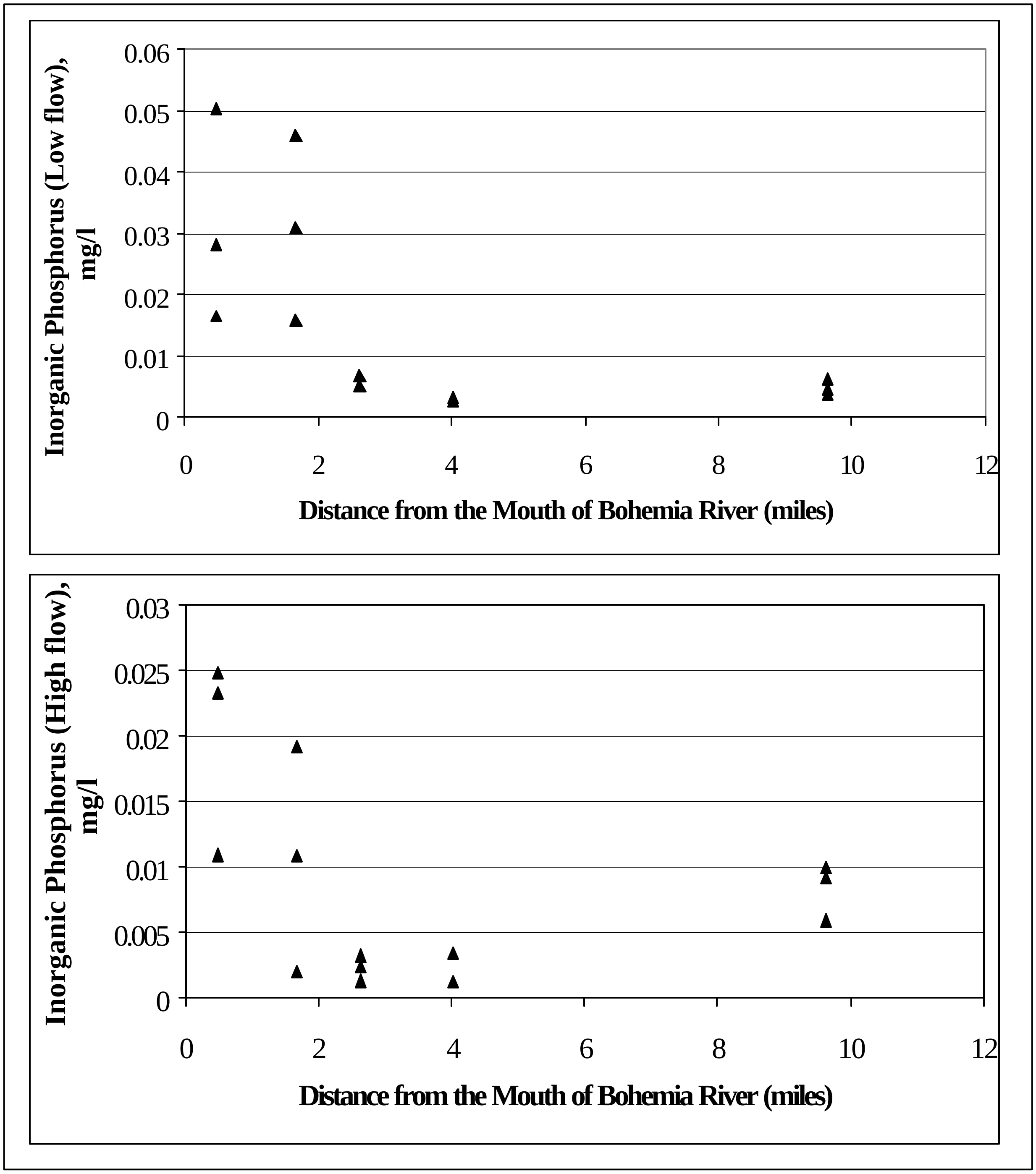

Figure A6: Longitudinal Profile of Inorganic Phosphorus Data

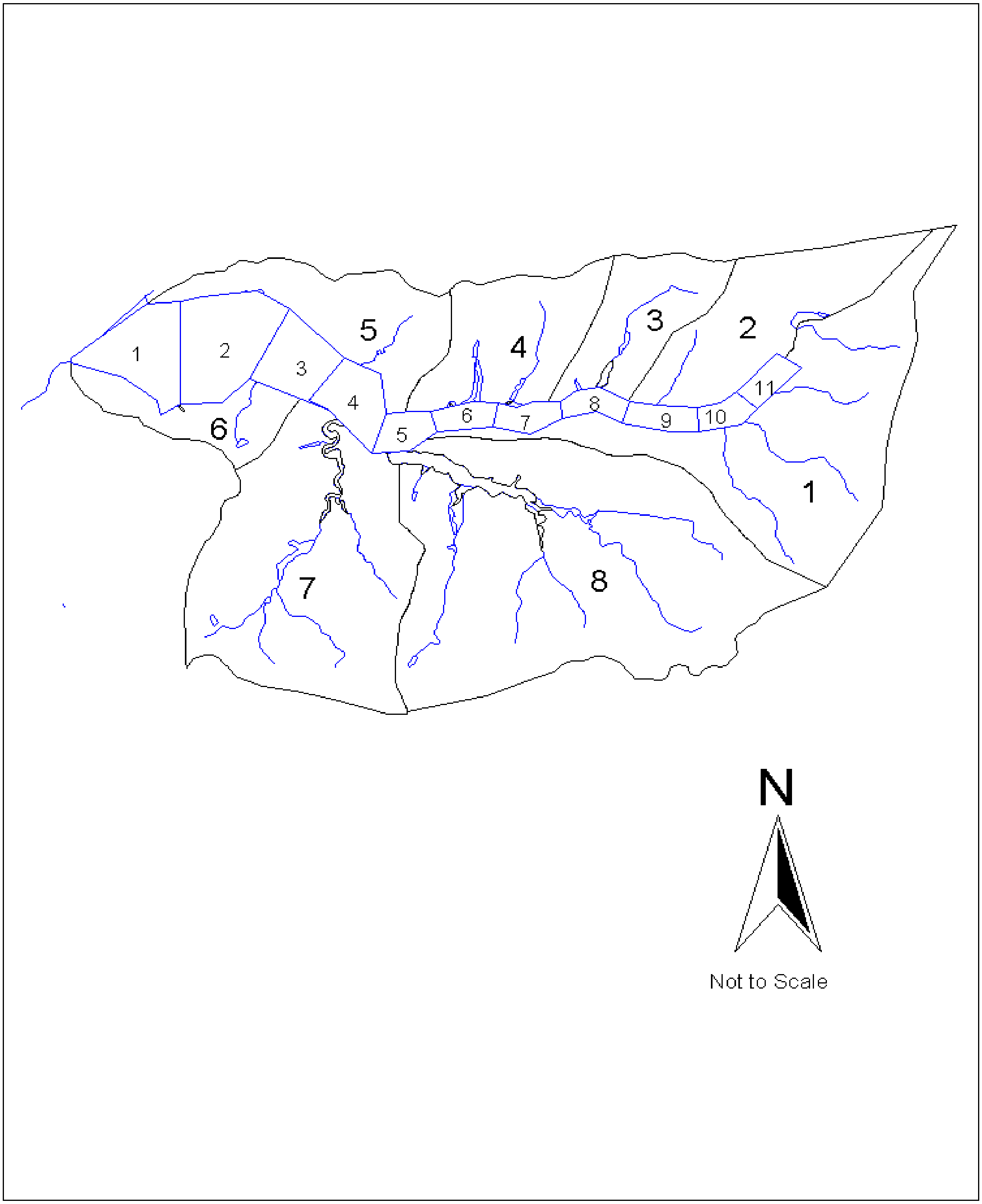

Figure A7: Model Segmentation of the BREM, including Subwatersheds

Table A2: Volumes, Characteristic Lengths, Interfacial Areas used in the BREM

Segment No.	Volume (m3)	Characteristic Length (m)	Interfacial Area (m2)
1	5415549	1530	3637.8
2	6260323	1735	3848.1
3	2712784	1757.5	2636.5
4	2482173	1647.5	830.6
5	1852223	1565	2011.7
6	751523.5	1415	608.1
7	712542	1490	448.7
8	509765	1555	464.5
9	209680	1575	199.9
10	37791	2085	62.2
11	48047	1265	2.34

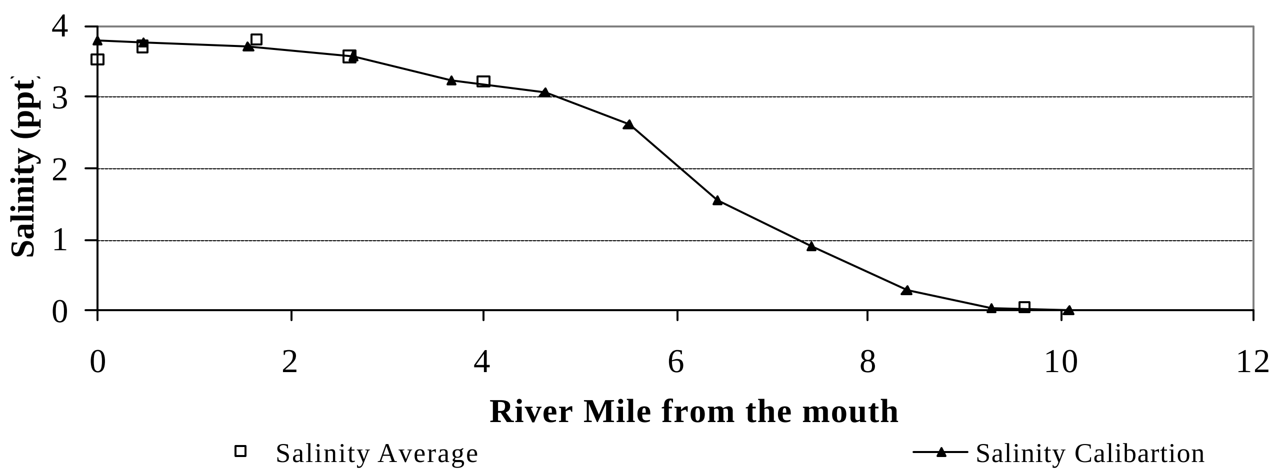

Figure A8: Results of the Calibration of Exchange Coefficients for Low Flow

Table A3: Dispersion Coefficients used in the BREM

Segment Nos.	Dispersion coefficients (m^2/sec)
1	20
2	15
3	12
4	9
5	5
6	3
7	1
8	0.8
9	0.5
10	0.3
11	0.1

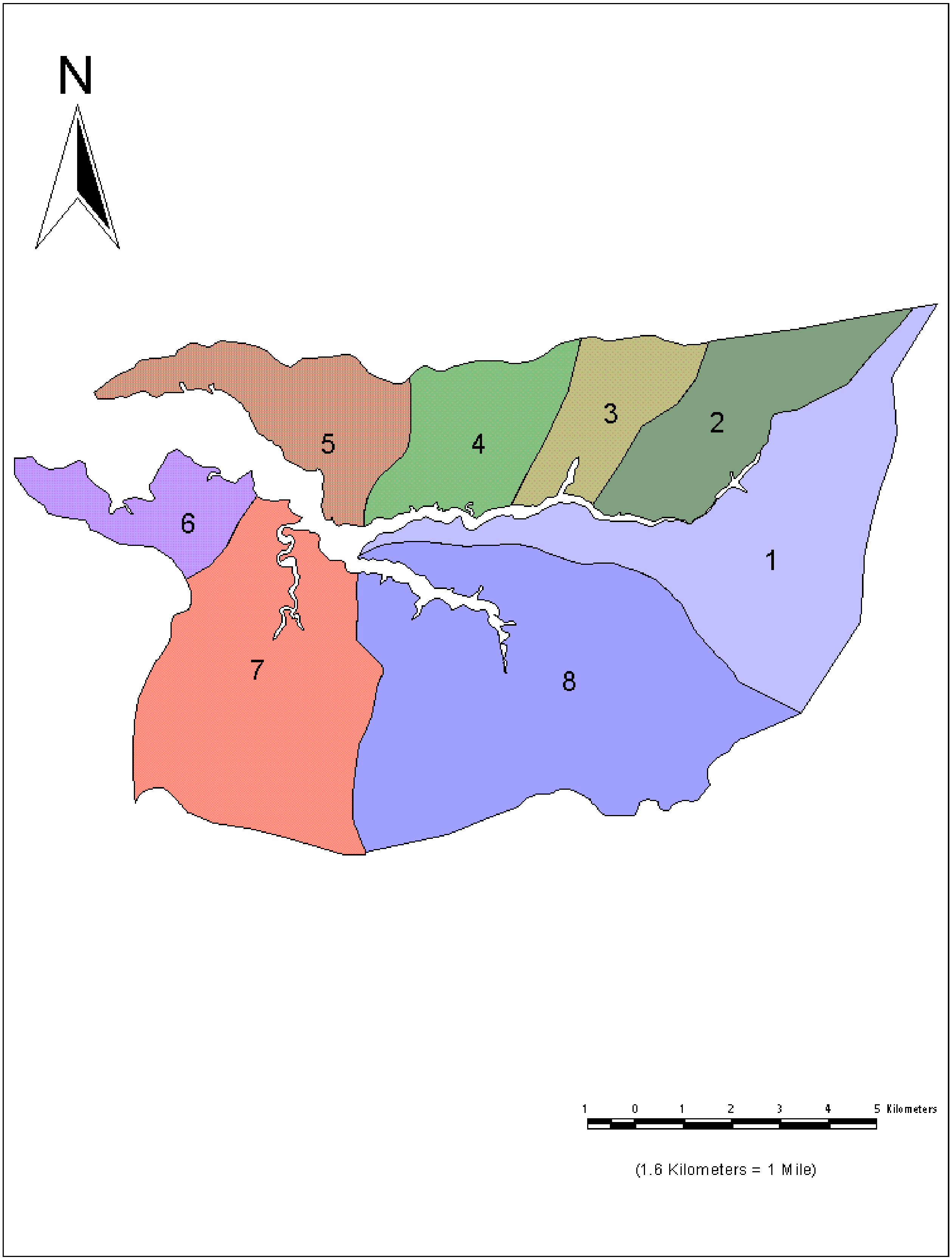

Figure A9: The Eight Subwatersheds of the Bohemia River Drainage Basin

Table A4: Subwatersheds flow for low, high flow and 7Q10 conditions

Subwatershed Nos.	Flow Symbols	Low flow (m^3/sec)	High flow (m^3/sec)	7Q10 flow (m^3/sec)
1	Q_1	0.0514	0.4207	0.0405
2	Q_2	0.0236	0.1930	0.0186
3	Q_3	0.0145	0.1183	0.0114
4	Q_4	0.0195	0.1599	0.0154
5	Q_5	0.0212	0.1733	0.0167
6	Q_6	0.0128	0.1045	0.0101
7	Q_7	0.0518	0.4237	0.0408
8	Q_8	0.0789	0.6457	0.0622

Table A5: Environmental Parameters for the Calibration of the Model

Segment	Ke (m^{-1})		T (^{0}C)		Salinity (gm/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)	
nos.	High flow	Low flow	High flow	Low flow	High flow	Low flow	High flow	Low flow	High flow	Low flow	High flow	Low flow
1	11.5	4.875	7.5	28.6	0.0	8.1	0.5	1.5	0	60	0	2.98
2	11.5	4.875	7.5	28.6	0.0	8.7	0.5	1.3	0	60	0	2.98
3	11.5	4.875	7.5	28.6	0.0	7.0	0.5	1.0	0	54	0	2.98
4	11.5	4.875	7.5	28.6	0.0	6.0	0.5	0.8	0	54	0	2.98
5	11.5	4.875	7.5	28.6	0.0	5.0	0.5	0.6	0	48	0	2.48
6	11.5	4.875	7.5	28.6	0.0	4.1	0.5	0.5	0	36	0	2.48
7	11.5	4.875	7.5	28.6	0.0	3.1	0.5	0.5	0	36	0	2.48
8	11.5	4.875	9.2	28.6	0.0	2.1	0.5	0.5	0	36	0	2.48
9	11.5	4.875	9.2	28.6	0.0	1.1	0.5	0.5	0	30	0	2.48
10	11.5	4.875	9.2	26.6	0.0	0.3	0.5	0.5	0	30	0	2.48
11	11.5	4.875	9.2	26.6	0.0	0.0	0.5	0.5	0	30	0	2.48

Table A6: EUTRO5 Kinetic Coefficients

Constant	Code	Value
Nitrification rate	K12C	0.12 *day* -1 at 20° C
temperature coefficient	K12T	1.04
Denitrification rate	K20C	0.08 *day* -1 at 20° C
temperature coefficient	K20T	1.045
Saturated growth rate of phytoplankton	K1C	2.0 *day* -1 at 20° C
temperature coefficient	K1T	1.066
Endogenous respiration rate	K1RC	0.065 *day*-1 at 20° C
temperature coefficient	K1RT	1.08
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	50
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	0.005 *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	450. *Ly/day*
BOD deoxygenation rate	KDC	0.20 *day* -1 at 20° C
temperature coefficient	KDT	1.047
Half saturation const. for carb. deoxygenation	KBOD	0.0
Reaeration rate constant	k2	0.20 *day* -1 at 20° C
Mineralization rate of dissolved organic nitrogen	K71C	0.015 *day*-1
temperature coefficient	K71T	1.08
Mineralization rate of dissolved organic phosphorus	K58C	0.12 *day* -1
temperature coefficient	K58T	1.08
Phytoplankton settling velocity		0.06 *m/day*
Organics settling velocity		0.01 *m/day*

Table A7: Contributing Watersheds to each Model Segment, and flows for the segments

Water quality Segments	Subwatershed contributions	Low flow m^3/sec	High flow m^3/sec	7Q10 flow m^3/sec
S1	-	-	-	-
S2	5	0.0026	0.0433	0.0021
S3	5+6	0.0085	0.1392	0.0067
S4	5+7	0.0317	0.5190	0.0250
S5	8	0.0395	0.6457	0.0311
S6	1+4	0.0044	0.0724	0.0035
S7	1+4	0.0066	0.1086	0.0052
S8	1+3	0.0085	0.1393	0.0067
S9	1+2	0.0061	0.1000	0.0048
S10	1	0.0103	0.1683	0.0081
S11	1+2	0.0185	0.3034	0.0146

Table A8: Nonpoint Source Concentrations for the Calibration of the Model for Low Flow

Segment Nos.	**NH4** *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	0.1123	0.7607	0.0474	2.7412	1.0000	6.17	0.4116	0.0267
2	0.0630	1.1967	0.0431	1.0467	3.3333	6.2	0.4043	0.0625
3	0.0630	1.1967	0.0431	1.0467	3.3333	6.2	0.4043	0.0625
4	0.0630	1.1967	0.0431	1.0467	3.3333	6.2	0.4043	0.0625
5*	0.2394	1.8531	0.1721	0.9922	4.3769	6.2	0.4223	0.0842
6	0.0630	1.1967	0.0431	1.0467	3.3333	6.2	0.4043	0.0625
7	0.0630	1.1967	0.0431	1.0467	3.3333	6.2	0.4043	0.0625
8	0.0630	1.1967	0.0431	1.0467	3.3333	6.2	0.4043	0.0625
9	0.0630	1.1967	0.0431	1.0467	3.3333	6.2	0.4043	0.0625
10	0.0630	1.1967	0.0431	1.0467	3.3333	6.2	0.4043	0.0625
11	0.0630	1.1967	0.0431	1.0467	3.3333	6.2	0.4043	0.0625

* Combined nonpoint source and Cecilton WWTP

Table A9: Concentrations and Flows for the Calibration of the Model for Low Flow for Segment 5

Source	**Flow** ***mgd***	**NH4** *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*
Nonpoint Source	0.91	0.06	1.20	0.04	1.05	3.33	6.2	0.40	0.06
Cecilton WWTP	0.05	3.45	13.8	2.52	0.00	23.37	6.7	0.75	0.48

Table A10: Nonpoint Source Concentrations for the Calibration of the Model for High flow

Segment Nos.	NH4 *mg/l*	NO23 *mg/l*	PO4 *mg/l*	CHL *a* *mg/l*	CBOD *mg/l*	DO *mg/l*	ON *mg/l*	OP *mg/l*
1	0.1120	1.0820	0.0298	2.0102	3.33	9.43	0.2554	0.0205
2	0.0830	1.0000	0.0084	5.2688	3.33	9.1	1.0875	0.0623
3	0.0830	1.0000	0.0084	5.2688	3.33	9.1	1.0875	0.0623
4	0.0830	1.0000	0.0084	5.2688	3.33	9.1	1.0875	0.0623
5*	0.0961	1.0412	0.0169	5.2509	3.40	9.1	1.0867	0.0637
6	0.0830	1.0000	0.0084	5.2688	3.33	9.1	1.0875	0.0623
7	0.0830	1.0000	0.0084	5.2688	3.33	9.1	1.0875	0.0623
8	0.0830	1.0000	0.0084	5.2688	3.33	9.1	1.0875	0.0623
9	0.0830	1.0000	0.0084	5.2688	3.33	9.1	1.0875	0.0623
10	0.0830	1.0000	0.0084	5.2688	3.33	9.1	1.0875	0.0623
11	0.0830	1.0000	0.0084	5.2688	3.33	9.1	1.0875	0.0623

* Combined nonpoint source and Cecilton WWTP

Table A11: Concentrations and Flows for the Calibration of the Model for High Flow for Segment 5

Source	Flow ***mgd***	NH4 *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*
Nonpoint Source	14.74	0.083	1.00	0.008	5.27	3.33	9.1	1.09	0.06
Cecilton WWTP	0.05	3.95	13.2	2.52	0.00	23.49	9.24	0.86	0.48

Low Flow Calibration

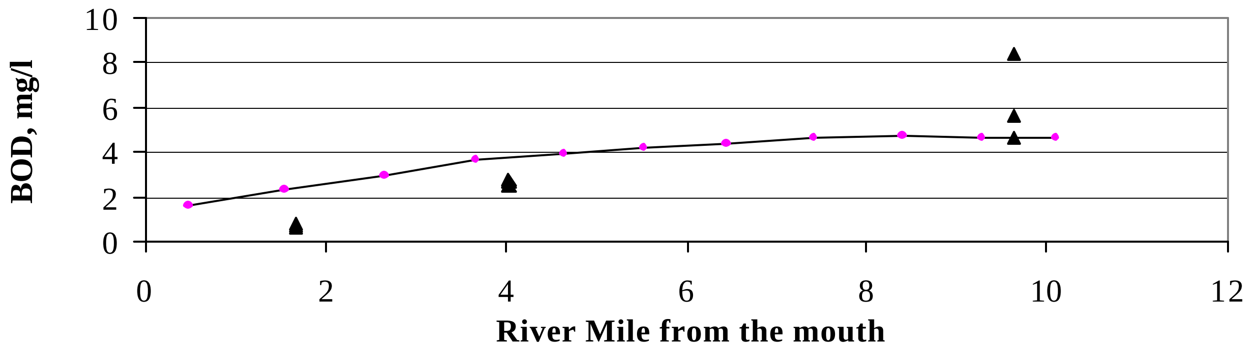

Figure A10: BOD vs. River Mile for the Calibration of the Model (Low flow)

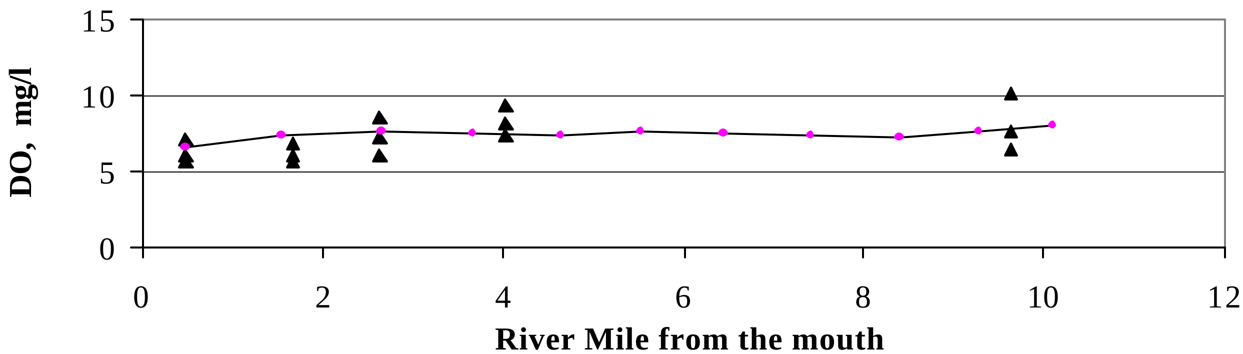

Figure A11: Dissolved Oxygen vs. River Mile for the Calibration of the Model (Low flow)

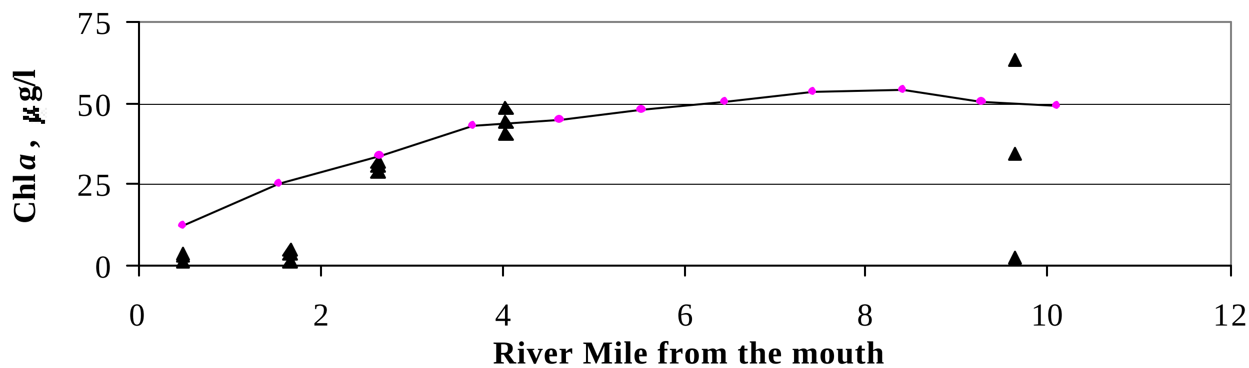

Figure A12: Chlorophyll *a* vs. River Mile for the Calibration of the Model (Low flow)

▲ **Monitoring Data** ___ **Calibration**

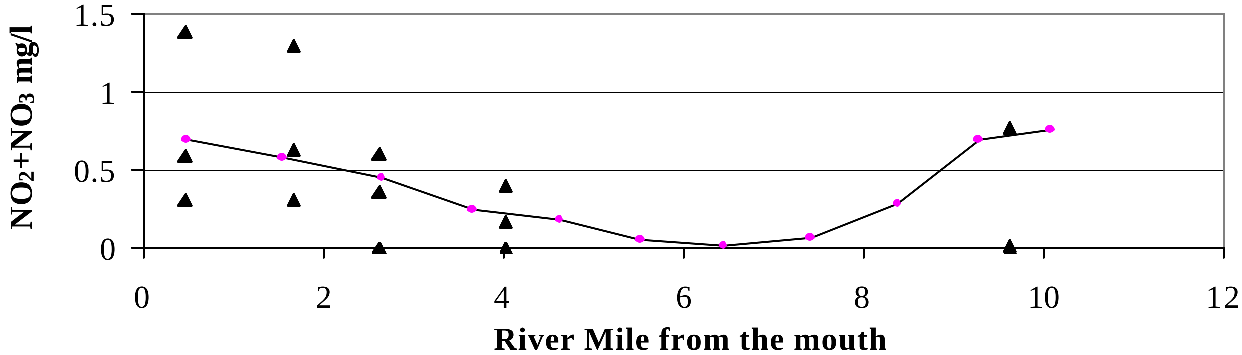

Figure A13: Nitrate (plus Nitrite) vs. River Mile for the Calibration of the Model (Low flow)

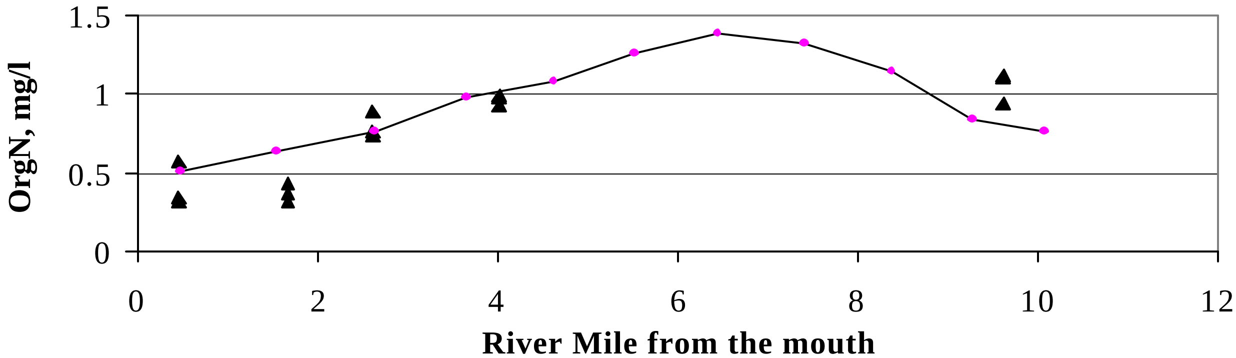

Figure A14: Organic Nitrogen vs. River Mile for the Calibration of the Model (Low flow)

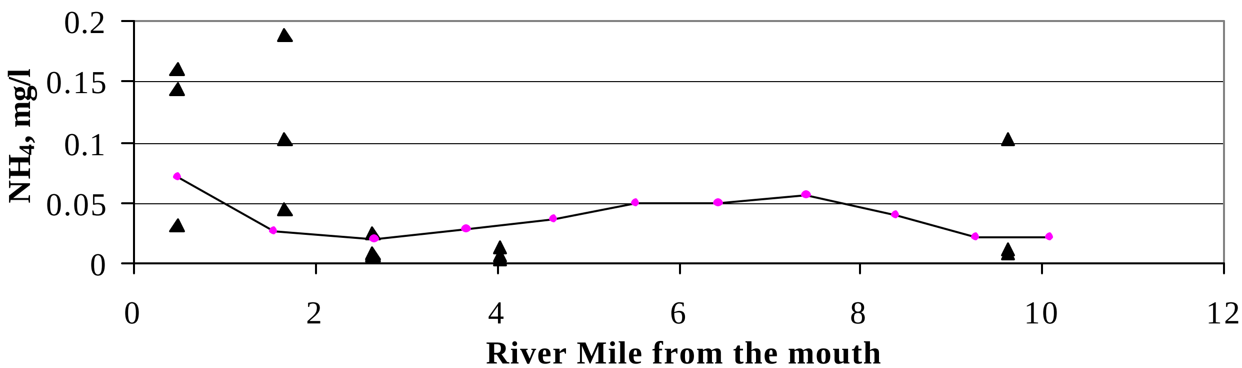

Figure A15: Ammonia vs. River Mile for the Calibration of the Model (Low flow)

Monitoring Data ___ **Calibration**

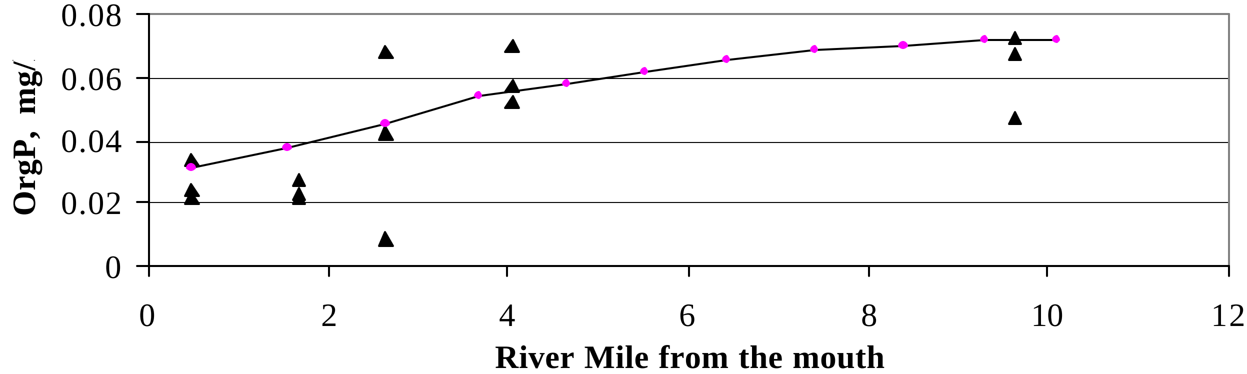

Figure A16: Organic Phosphorus vs. River Mile for the Calibration of the Model (Low flow)

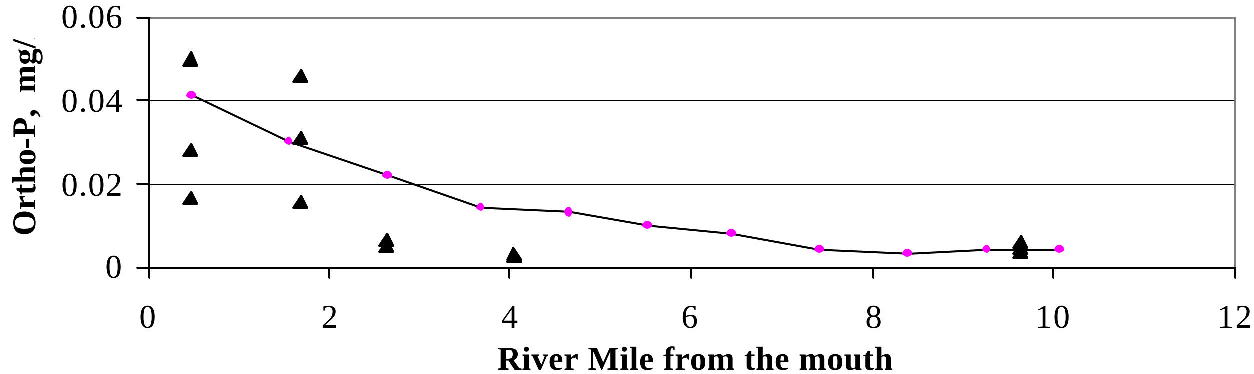

Figure A17: Ortho-Phosphate vs. River Mile for the Calibration of the Model (Low flow)

▲ **Monitoring Data** ___ **Calibration**

High Flow Calibration

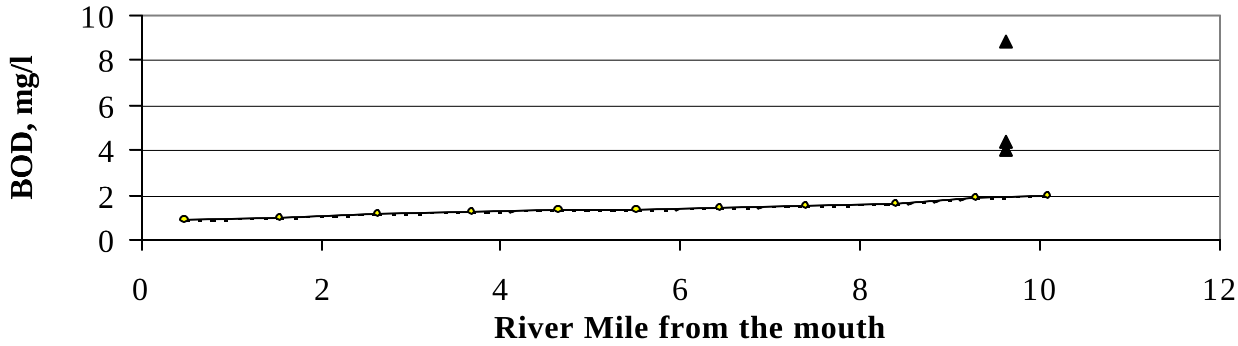

Figure A18: BOD vs. River Mile for the Calibration of the Model (High flow)

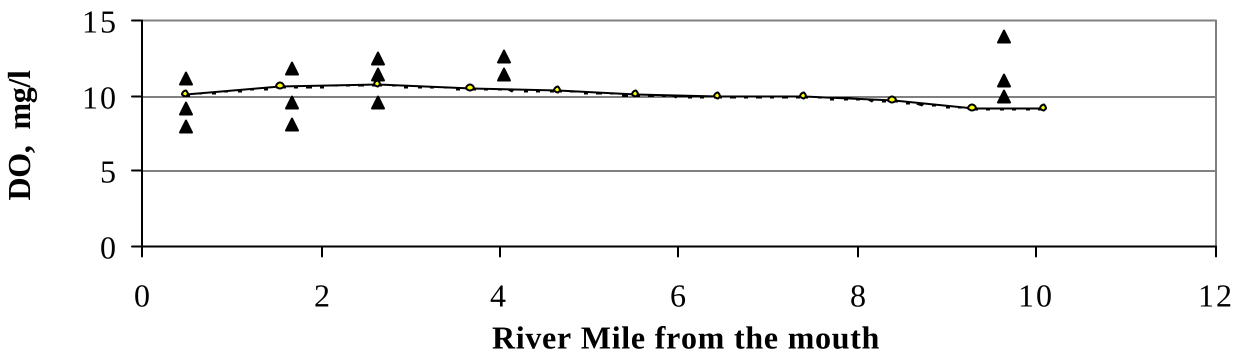

Figure A19: Dissolved Oxygen vs. River Mile for the Calibration of the Model (High Flow)

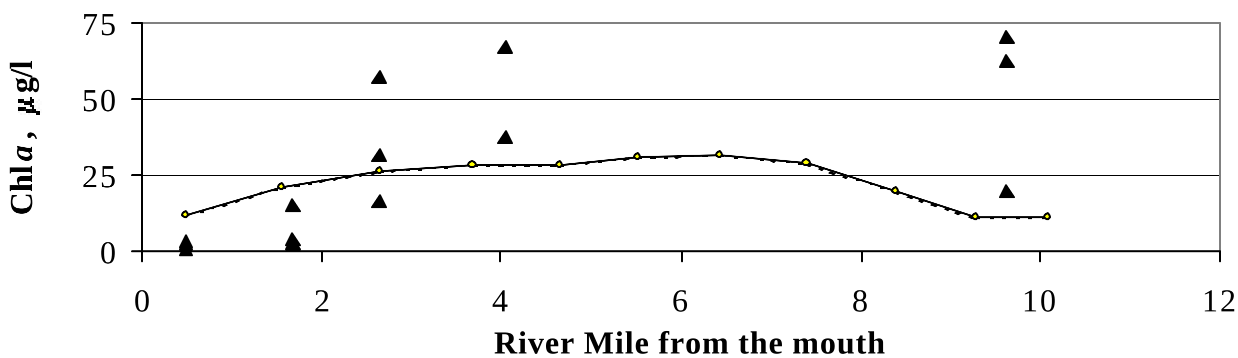

Figure A20: Chlorophyll *a* vs. River Mile for the Calibration of the Model (High flow)

▲ Monitoring Data **___ Calibration**

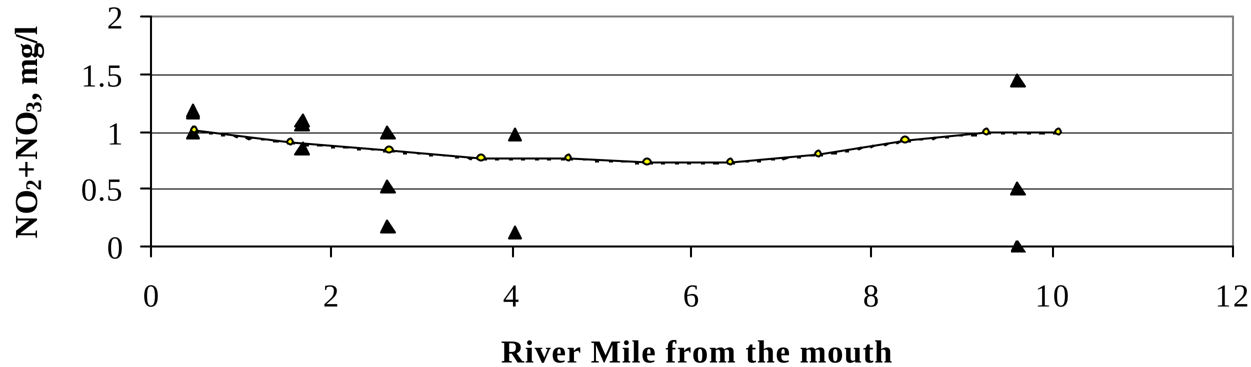

Figure A21: Nitrate (plus Nitrite) vs. River Mile for the Calibration of the Model (High flow)

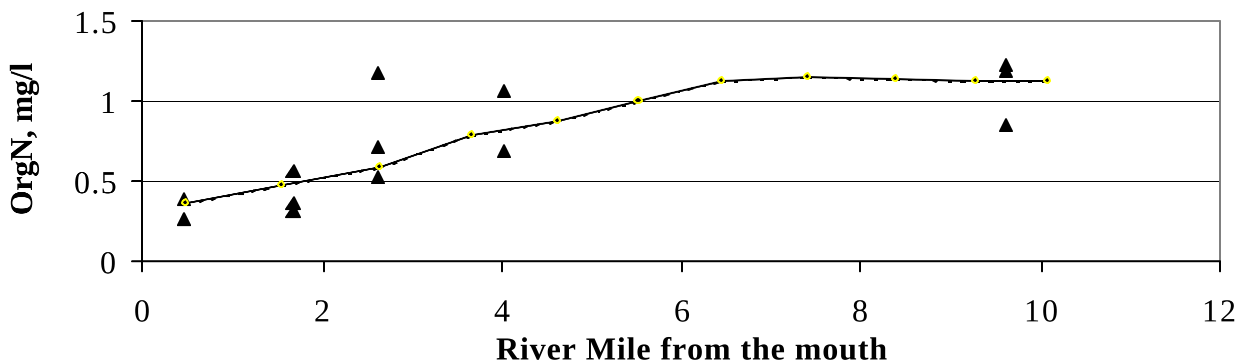

Figure A22: Organic Nitrogen vs. River Mile for the Calibration of the Model (High flow)

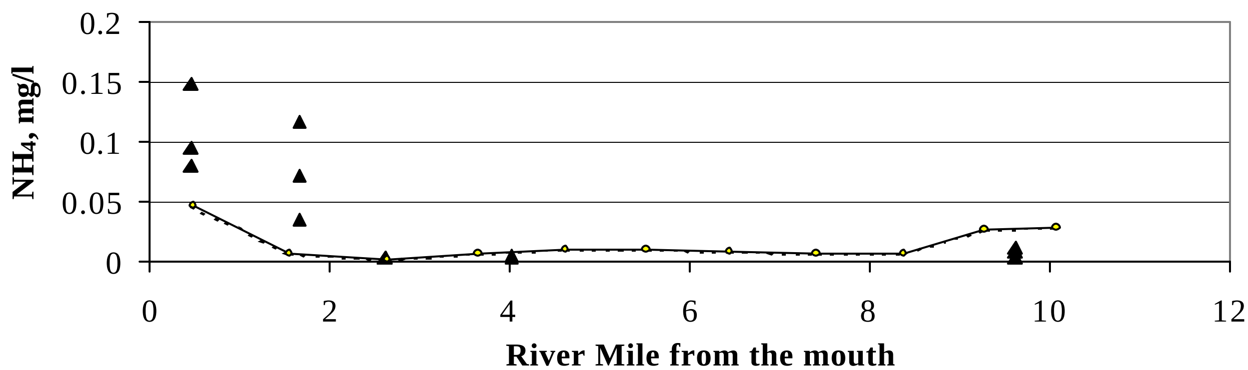

Figure A23: Ammonia vs. River Mile for the Calibration of the Model (High flow)

▲ **Monitoring Data** ___ **Calibration**

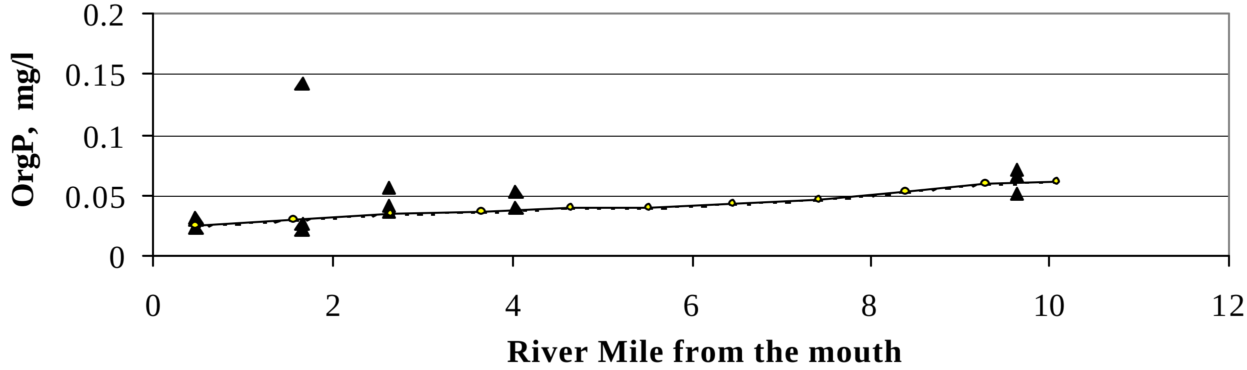

Figure A24: Organic Phosphorus vs. River Mile for the Calibration of the Model (High flow)

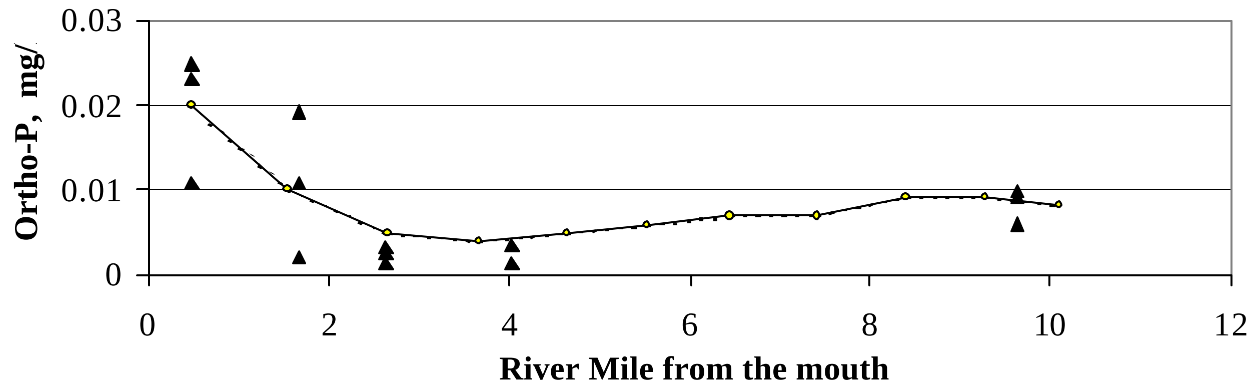

Figure A25: Ortho-Phosphate vs. River Mile for the Calibration of the Model (High flow)

▲ **Monitoring Data** ___ **Calibration**

Table A12: Nonpoint Source Concentrations for the Base-line Low Flow Condition

Segment Nos.	NH4 *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	0.1123	0.7607	0.0474	2.7412	1.0000	6.17	0.4116	0.0267
2	0.0630	1.1967	0.0431	1.0467	3.3333	6.2	0.4043	0.0625
3	0.0630	1.1967	0.0431	1.0467	3.3333	6.2	0.4043	0.0625
4	0.0630	1.1967	0.0431	1.0467	3.3333	6.2	0.4043	0.0625
5*	0.4061	2.4732	0.4641	0.9407	5.3627	6.3	0.4393	0.1372
6	0.0630	1.1967	0.0431	1.0467	3.3333	6.2	0.4043	0.0625
7	0.0630	1.1967	0.0431	1.0467	3.3333	6.2	0.4043	0.0625
8	0.0630	1.1967	0.0431	1.0467	3.3333	6.2	0.4043	0.0625
9	0.0630	1.1967	0.0431	1.0467	3.3333	6.2	0.4043	0.0625
10	0.0630	1.1967	0.0431	1.0467	3.3333	6.2	0.4043	0.0625
11	0.0630	1.1967	0.0431	1.0467	3.3333	6.2	0.4043	0.0625

* Combined nonpoint source and Cecilton WWTP

Base-line Low Flow Scenario

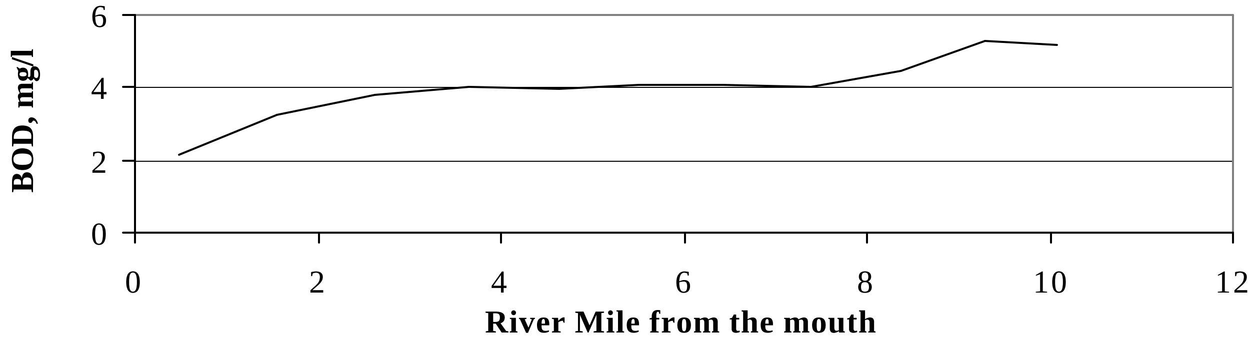

Figure A26: BOD vs. River Mile for the Base-line Low Flow Scenario

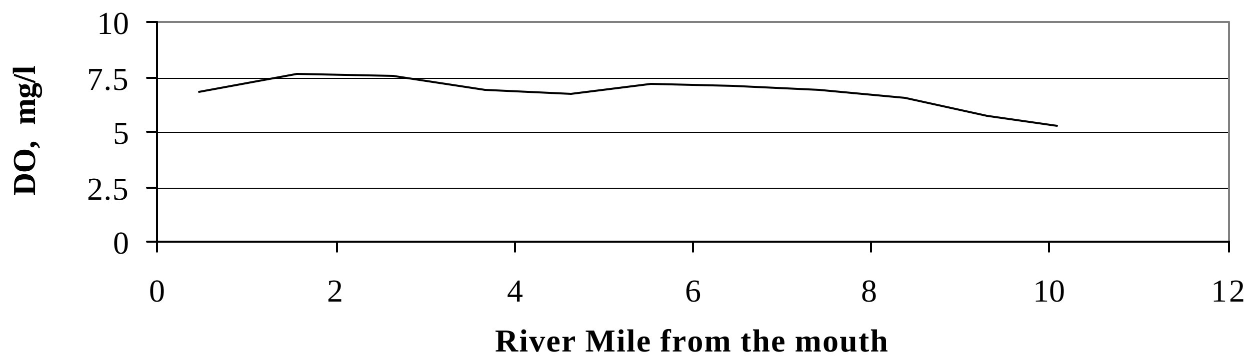

Figure A27: Dissolved Oxygen vs. River Mile for the Base-line Low Flow Scenario

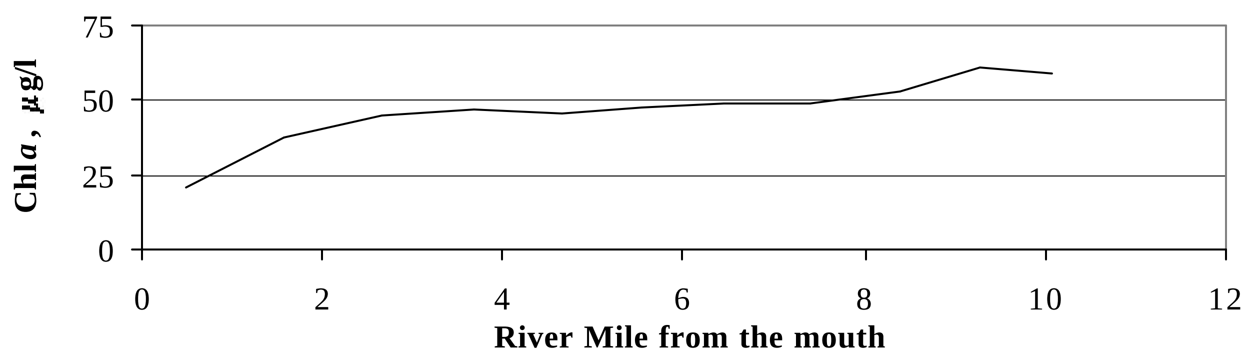

Figure A28: Chlorophyll *a* vs. River Mile for the Base-line Low Flow Scenario

_____ **Base-line low flow condition**

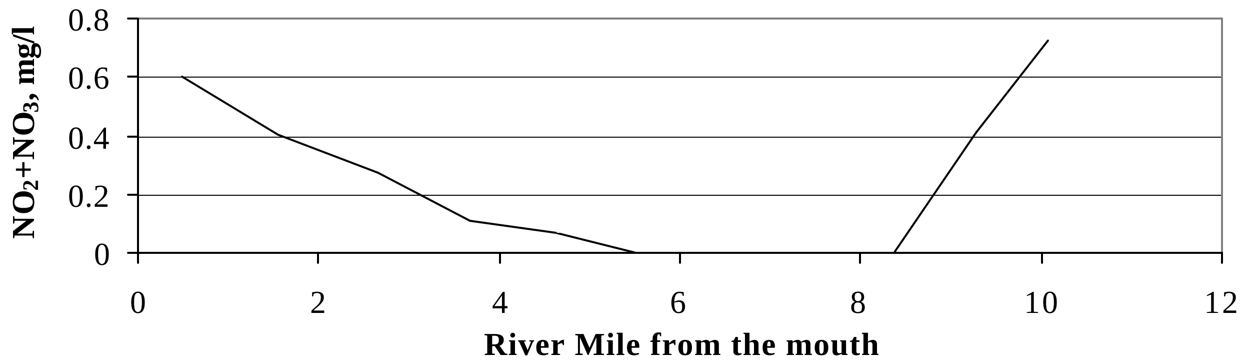

Figure A29: Nitrate (plus Nitrite) vs. River Mile for the Base-line Low Flow Scenario

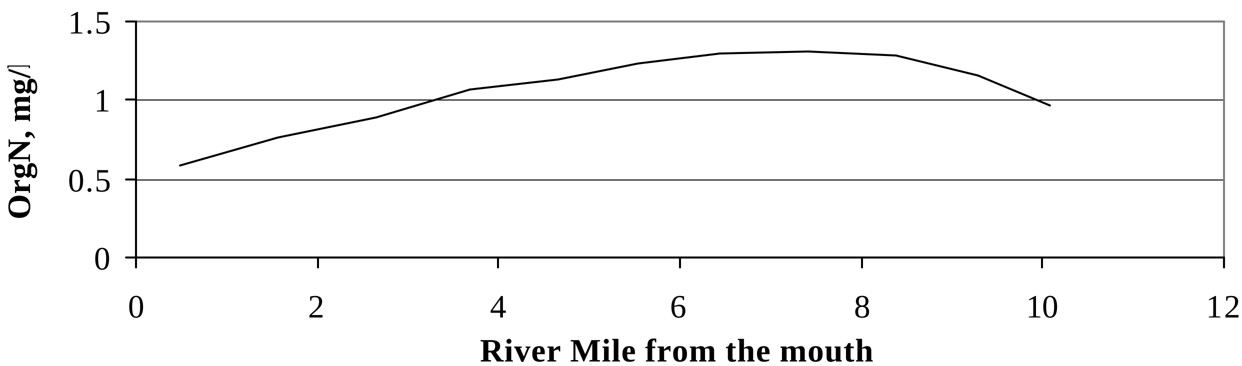

Figure A30: Organic Nitrogen vs. River Mile for the Base-line Low Flow Scenario

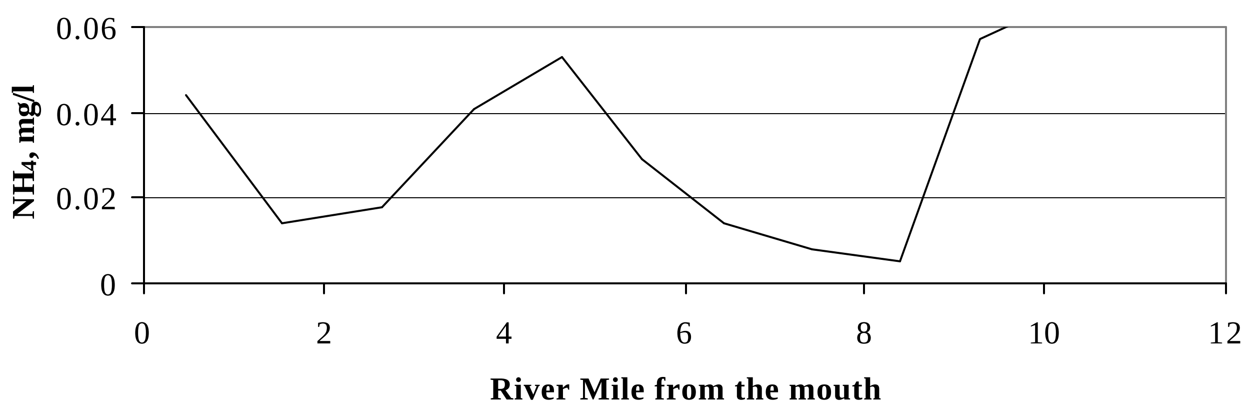

Figure A31: Ammonia vs. River Mile for the Base-line Low Flow Scenario

_____ **Base-line low flow condition**

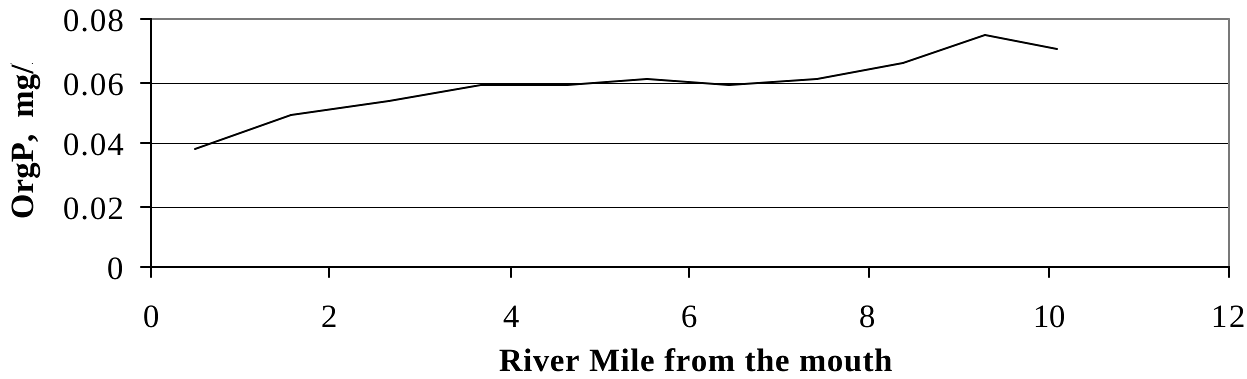

Figure A32: Organic Phosphorus vs. River Mile for the Base-line Low Flow Scenario

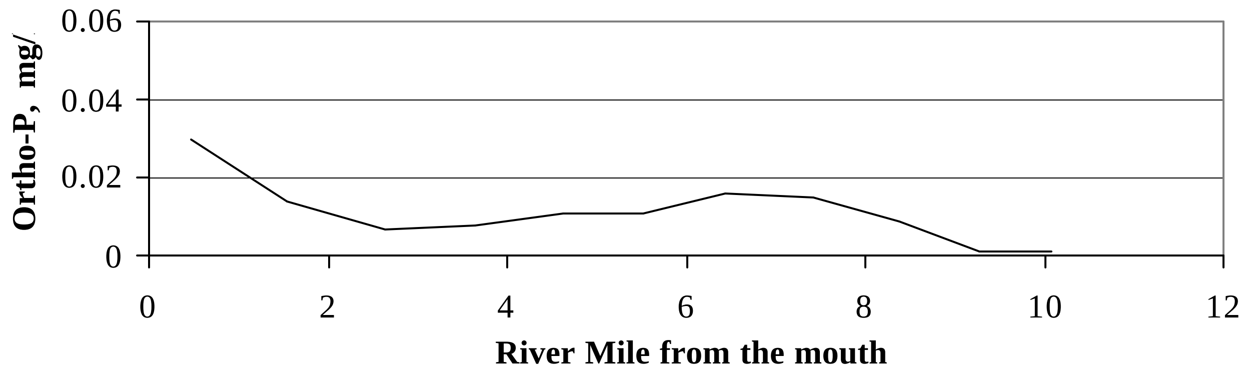

Figure A33: Ortho-Phosphorus vs. River Mile for the Base-line Low Flow Scenario

Base-line low flow condition

Future Low Flow TMDL Scenario Results

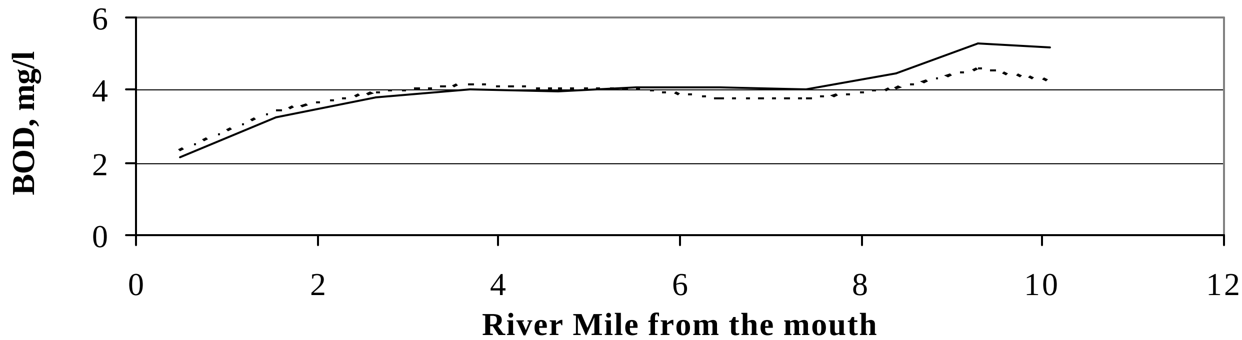

Figure A34: BOD vs. River Mile for the Future Low flow TMDL scenario

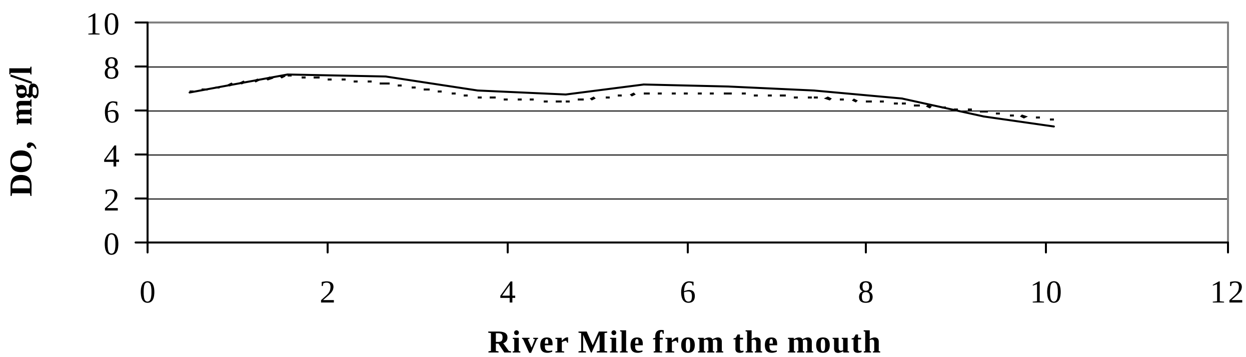

Figure A35: Dissolved Oxygen vs. River Mile for the Future Low flow TMDL scenario

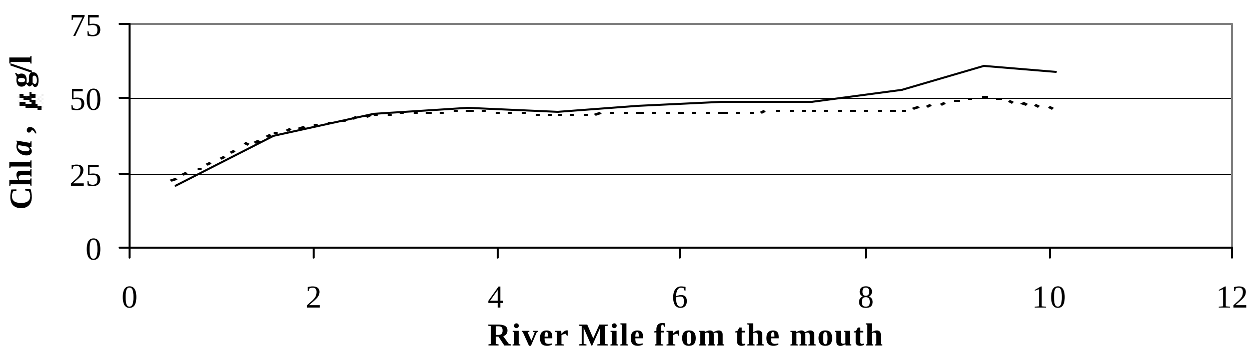

Figure A36: Chlorophyll *a* vs. River Mile for the Future Low flow TMDL scenario

___ Base-line Low flow condition **…… Future Low flow TMDL condition**

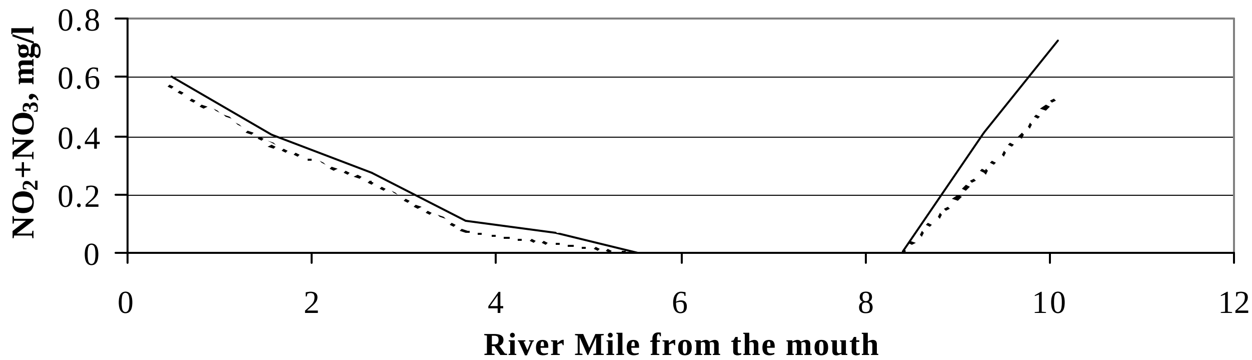

Figure A37: Nitrate (plus Nitrite) vs. River Mile for the Future Low flow TMDL scenario

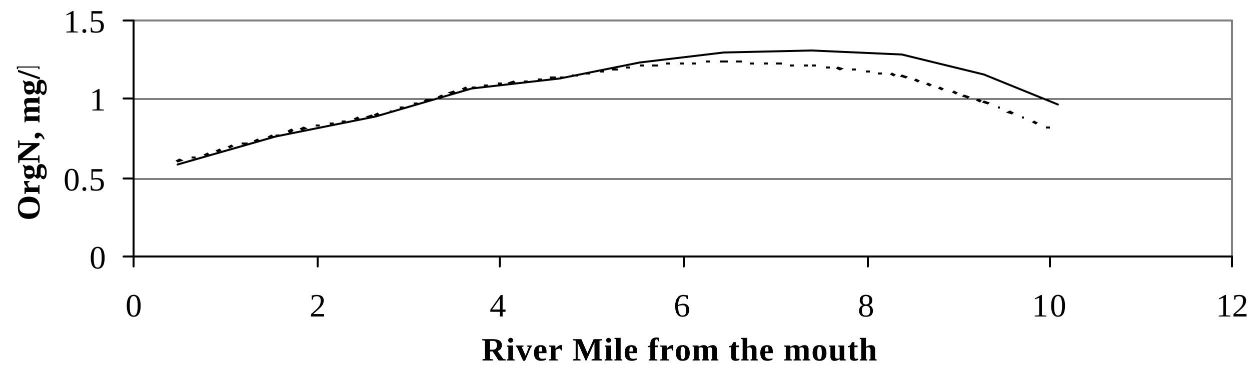

Figure A38: Organic Nitrogen vs. River Mile for the Future Low flow TMDL scenario

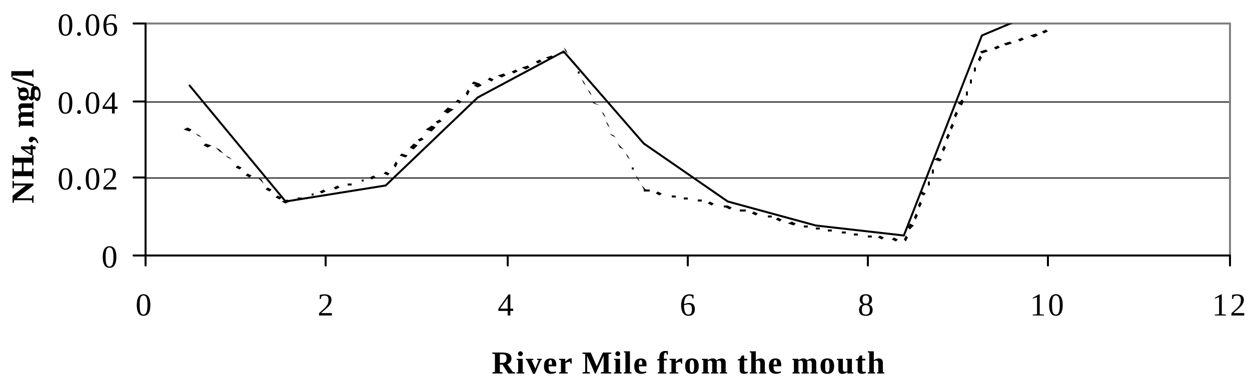

Figure A39: Ammonia vs. River Mile for the Future Low flow TMDL scenario

___ Base-line Low flow condition **…… Future Low flow TMDL condition**

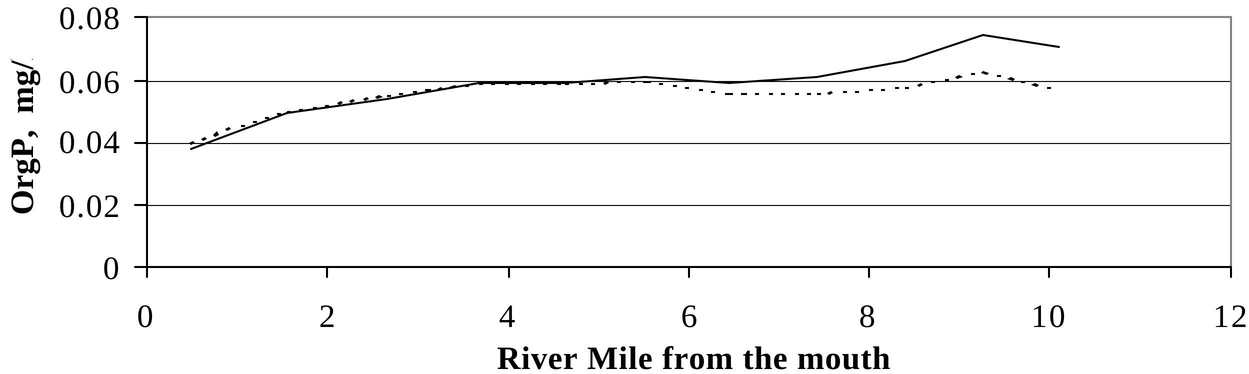

Figure A40: Organic Phosphorus vs. River Mile for the Future Low flow TMDL scenario

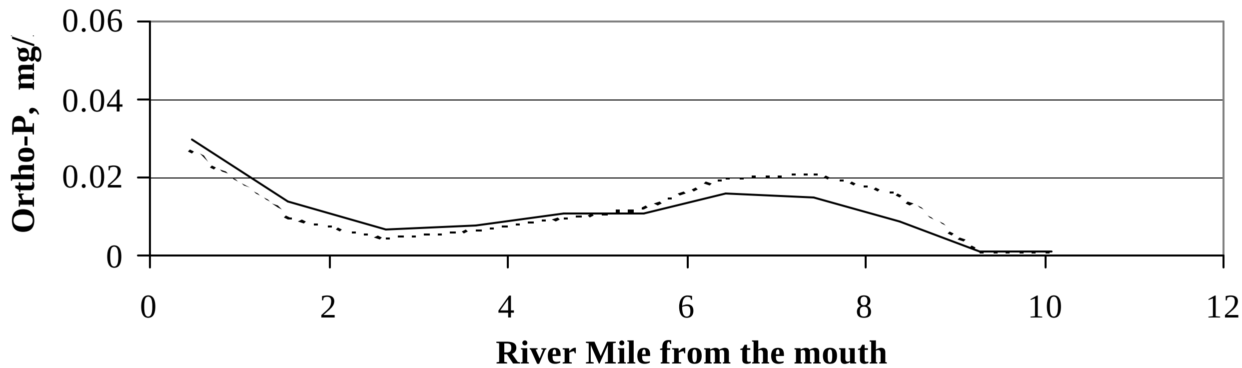

Figure A41: Ortho-Phosphorus vs. River Mile for the Future Low flow TMDL scenario

___ Base-line Low flow condition **…… Future Low flow TMDL condition**

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