Report Version: January 22, 2001

APPENDIX A

Total Maximum Daily Loads of
Nitrogen and Phosphorus for
the Chicamacomico River
Dorchester, Maryland

Appendix A

MODELING FRAMEWORK

The computational framework chosen for the modeling of water quality of the Chicamacomico 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 February 12, March 16, March 23, July 21, August 18, and September 15, 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 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 and March 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 Chicamacomico 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 Chicamacomico River Eutrophication Model (CREM) extends from the confluence of the Chicamacomico River and the Transquaking River for about 16.3 miles up the mainstem of the Chicamacomico River. Following a review of the bathymetry for Chicamacomico River, the model was divided into 15 segments. Figure A7 shows the model segmentation for the development of CREM. Table A2 lists the volumes, characteristic lengths and interfacial areas of the 15 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 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 regression equation for the low flow and MDE high flow data was used for the high flow. 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 on the basis of delineating the Chicamacomico drainage basin 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 15 segments developed for the CREM. The CREM was calibrated for two sets of flow conditions: high flow and low flow. The high flow corresponds to the months of February and March, while the low flow corresponds to the months of July, August and September.

The high flow for each subwatershed was estimated based on an average value calculated from two sets of high flow measurements (February 12, 1998 & March 23, 1998) at station TRQ0224 and station CCM0160. The estimated high flow was found to be consistent with the average flows for the months of February and March of 1998 for a nearby USGS gage #01488600 (At

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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 |

Adamsville in Marshyhope River Basin). A ratio of flow to drainage area was calculated from the two water quality stations, then multiplied by the area of each of the subwatershed to obtain the high flows. The low flows used in the model from different subwatersheds of the Chicamacomico River Basin were based on a regression equation. The regression equation (which includes the abandoned USGS gauge, Station No. 01490000 in Salemjust above Big Millpond) is based on 30 years of flow data encompassing USGS gages in the entire Delmarva Peninsula region. This regression equation gives flow for a particular month based on watershed area. Flows were calculated for the months of July, August, and September and were then averaged. The estimated flows from the USGS regression analysis closely correspond to one instantaneous flow measurement taken during the field surveys. The average flow was based on data from an abandoned USGS gage on the Chicamacomico River, and was 18.6 cfs. Table A4 presents flows from different subwatersheds during high, low and average flows.

For high flow, each sub-watershed was assumed to contribute a flow to the Chicamacomico 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 CREM.

Point and Nonpoint Source Loadings

There are no significant point sources contributing load to the Chicamacomico River. Nonpoint source loadings were estimated for both average annual flow and low flow conditions. Loads for low flow conditions were estimated as the product of observed low flow concentrations and estimated flows described above. Being observed loads, they account for all sources.

Average annual loads were determined using land use loading coefficients. The land use information was based on 1997 Maryland Office of Planning 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, loads coming from urban development, agriculture, and forest land.

Loads for the calibration of the model were calculated using data from two water quality stations within the Chicamacomico River Basin. Data from station CCM0002 was used as a boundary condition for segment 1 of the CREM, and data from station CCM0160 was used as a boundary condition for segment 15. The boundary conditions for the remaining non-tidal boundaries were based on data from station CCM0160. This is the only free flowing station in the watershed and it was assumed to be a reasonable representation of water quality. 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 Chicamacomico 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 0.017 *m/day*, and phytoplankton was estimated to settle through the water column at a rate of 0.086 *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 CREM reaches based on observed environmental conditions and literature values (Institute of Natural Resources, 1986). The highest SOD values were assumed to occur in the lower reaches and the upper reaches (in the pond) 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 3.0 $g\ O_2/m^2 day$ was used.

Kinetic Coefficients

The water column kinetic coefficients are universal constants used in the CREM 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 simulated a long period of time to reach 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 1998 data. Tables A7, A8 & A9 shows the nonpoint source flows and loads associated with the calibration input file. 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 an excellent job of capturing the peak chlorophyll *a*, and BOD concentrations and also the general trend (Figure A10, A12). The ability to simulate the peak nitrate plus nitrite concentrations was limited by the sudden change in the observed concentrations (Figure A13). The model captured the ammonia and organic nitrogen concentrations very well (Figure A14, and A15). It was also able to replicate the organic phosphorus and the ortho-phosphate trends although it did not capture the peak values (Figure A16, and A17).

The EUTRO5.1 model for high flow was calibrated with February and March 1998 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. One exception is for organic phosphorus and the ortho-phosphate; however, this is not very significant given that the range of values is very small.

SYSTEM RESPONSE

The EUTRO5.1 model of Chicamacomico River was applied to several different nonpoint source loading conditions under various stream flow conditions to project the impacts of nutrients on algal production, as 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 stream under current loading conditions during low flow. The low flow was estimated using a regression analysis as described above. The total nonpoint source loads were computed as the product of observed 1998 base-flow concentrations and the estimated low flow. Because the loads are based on observed concentrations, they account for all background and human-induced sources. All the environmental parameters used for the low flow calibration of the model remained the same for scenario 1.

The second scenario represents the expected conditions of the stream during average flow. The average annual flow was estimated to be 18.6 cfs based on data from the abandoned USGS gage in the Chicamacomico as described above. Nonpoint source load estimation methods, based on EPA Chesapeake Bay model output, are described above. All the environmental parameters remained the same except for the temperature. A summer average temperature of 27.5 ^{o}C was used for all segments, which is a conservative. The boundary and initial conditions values for CHL*a*, DO, and BOD were assumed to be the same as for the low flow condition. The nonpoint source loads for model scenarios 1 and 2 can be seen in Table A10 and Table A11.

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 response in the River for the maximum allowable loads for low flow and average annual cases 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 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. However, the percent controllable was applied to the low flow loads as well as the average annual loads.

The reduction in nutrients also affects the initial concentrations of chlorophyll *a* in the river for the model run. The amount of nitrogen and phosphorus available for algae growth was calculated after the reduction in nutrient loads, to help estimate the amount of chlorophyll *a* at the boundaries. The amount of chlorophyll *a* that could be grown was calculated twice, once assuming nitrogen was the limiting nutrient, and again assuming phosphorus was the limiting nutrient. The lower of two values was compared to the low flow boundary value for chlorophyll *a*, and lower of these two were then taken to be the boundary for average flow. All calculated values for the chlorophyll *a* boundaries were found to be higher than the low flow chlorophyll *a* boundaries and hence low flow chlorophyll *a* boundaries were used as a conservative assumption.

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 expected condition 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 $0.5 gO_2/m^2\ day$.

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 scenario one. 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 $50\mu g/l$, and the dissolved oxygen criterion of not less than 5.0mg/l. 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.

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 scenario 2. The nitrogen and phosphorus loads were reduced from the scenario 2 baseline to meet chlorophyll *a*, and dissolved oxygen standards in the water as in scenario 3. A 3% margin of safety was included in the load calculation. All the environmental parameters (except nutrient fluxes and SOD) and kinetic coefficients used for the calibration of the model remained the same as scenario 2. The temperature was the same as in the scenario 2.

For both the third and the fourth scenarios, the boundary conditions at the confluence of Transquaking and Chicamacomico reflected the conditions established by the Transquaking TMDL analysis for the respective flow regimes. For the fourth scenario a reduction of 35% plus a 3% margin of safety was applied in order to be consistent with the reduction done in the Chicamacomico portion of the basin while establishing the TMDL for Transquaking River.

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 on the basis of 1997 land use, and projected year-2000 nutrient loading rates from the EPA Chesapeake Bay watershed model.

The CREM 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 CREM 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 scenarios 1 and 2 can be seen in Figures A26-A41. In scenario 1, the peak chlorophyll *a* level is just around the threshold of 50 µg/l, but the dissolved oxygen level falls below the water quality standard of 5 mg/l. Scenario 2 does not show any violation for the standards, but it is important to consider, because establishment of the Transquaking TMDL required a reduction of 38% in the average loads from the Chicamacomico portion of the watershed.

Future Condition TMDL Scenarios:

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

4. *Average Annual Flow:* Simulates the future condition of maximum allowable loads under average stream flow and average annual loading conditions to meet down-stream water quality in the Transquaking River.

The results of the third scenario indicate that, under summer low flow conditions, the water quality target for dissolved oxygen and chlorophyll *a* is satisfied at all locations along the mainstem of the Chicamacomico River. The results of scenario 3 and scenario 4 are presented in Figures A42-A57.

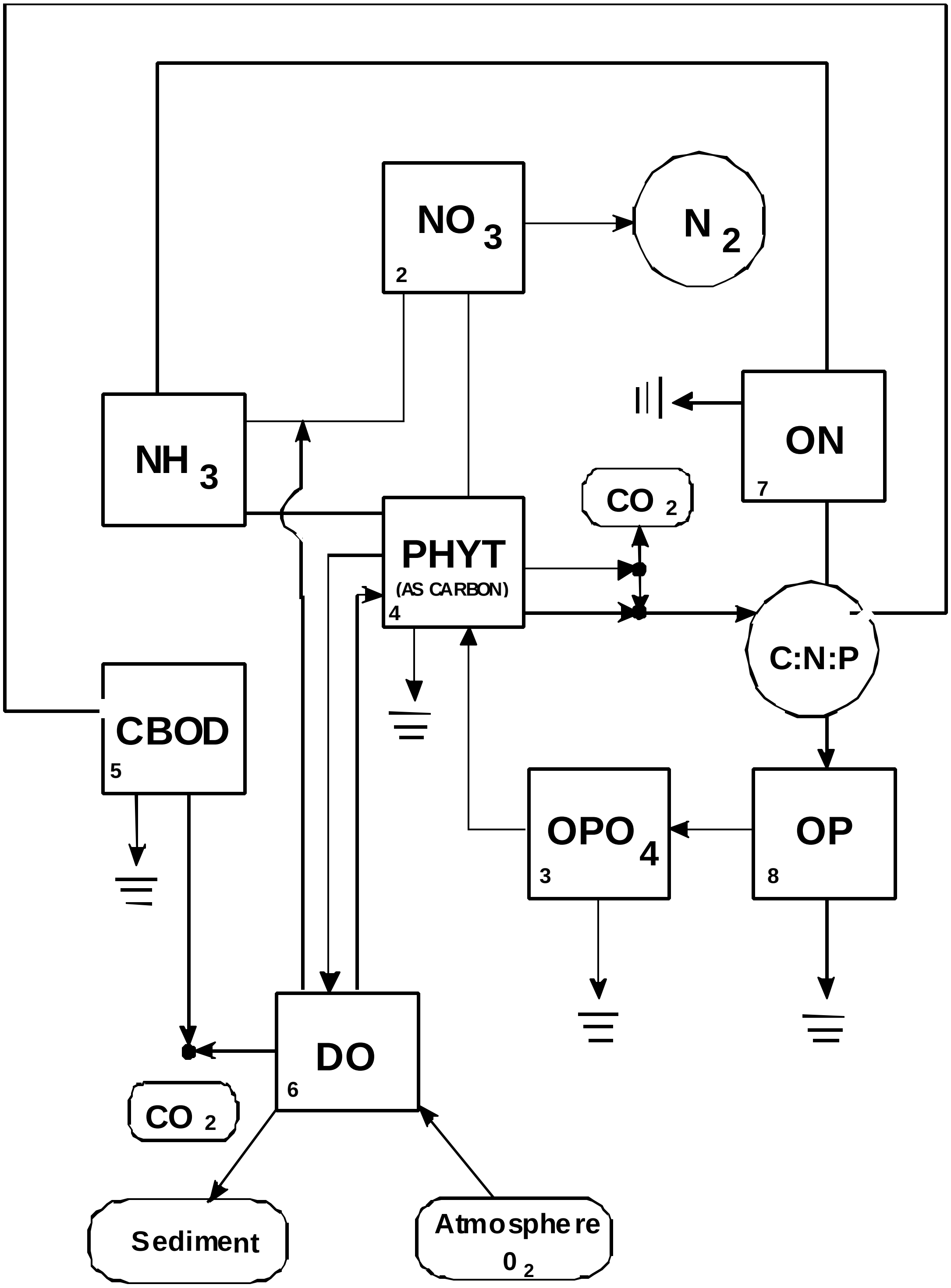

Figure A1: State Variables and Kinetic Interactions in EUTRO5

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 (15th ed.) #1002G. Chlorophyll. Pp 950-954
BOD_5	mg/l	0.01 mg/l	Oxidation ** EPA No. 405

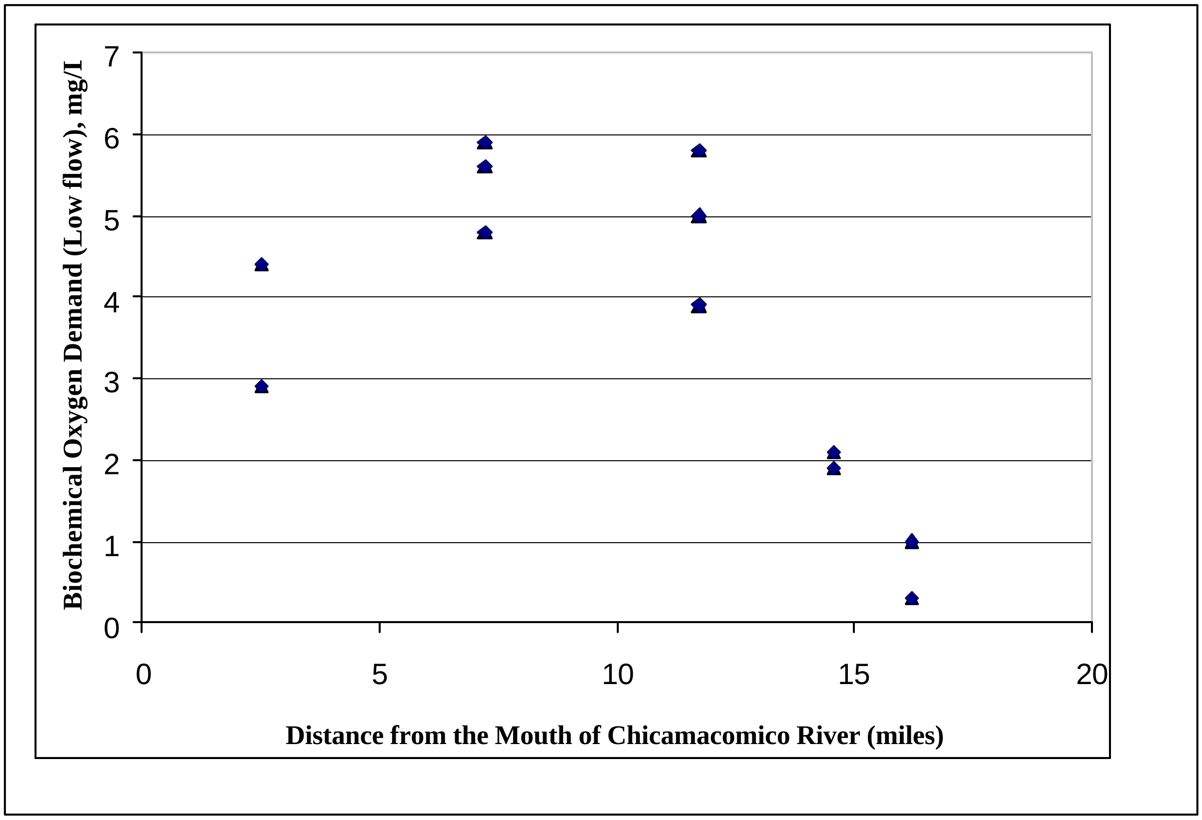

Figure A2: Longitudinal Profile of BOD Data

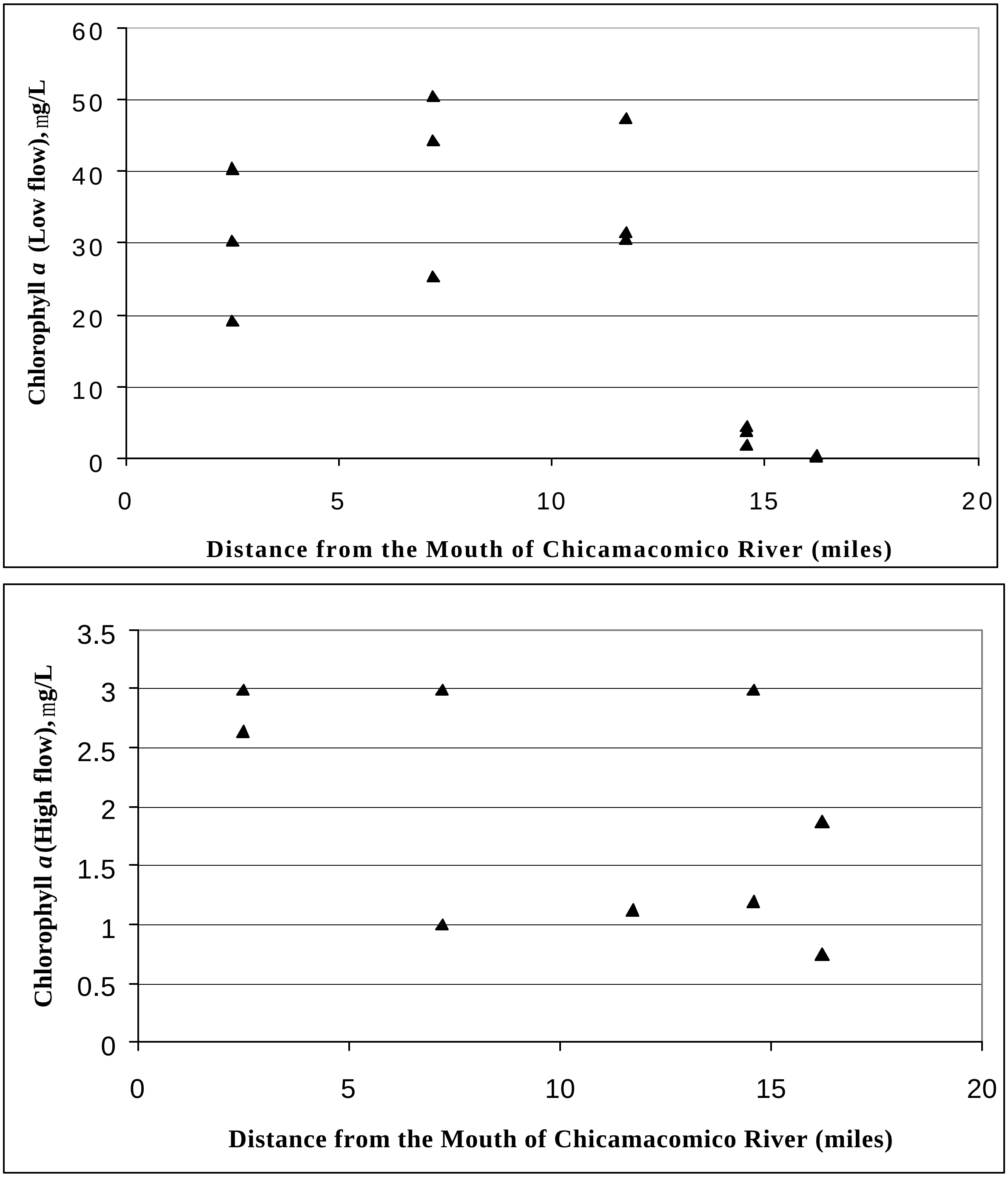

Figure A3: Longitudinal profile of Chlorophyll *a* data

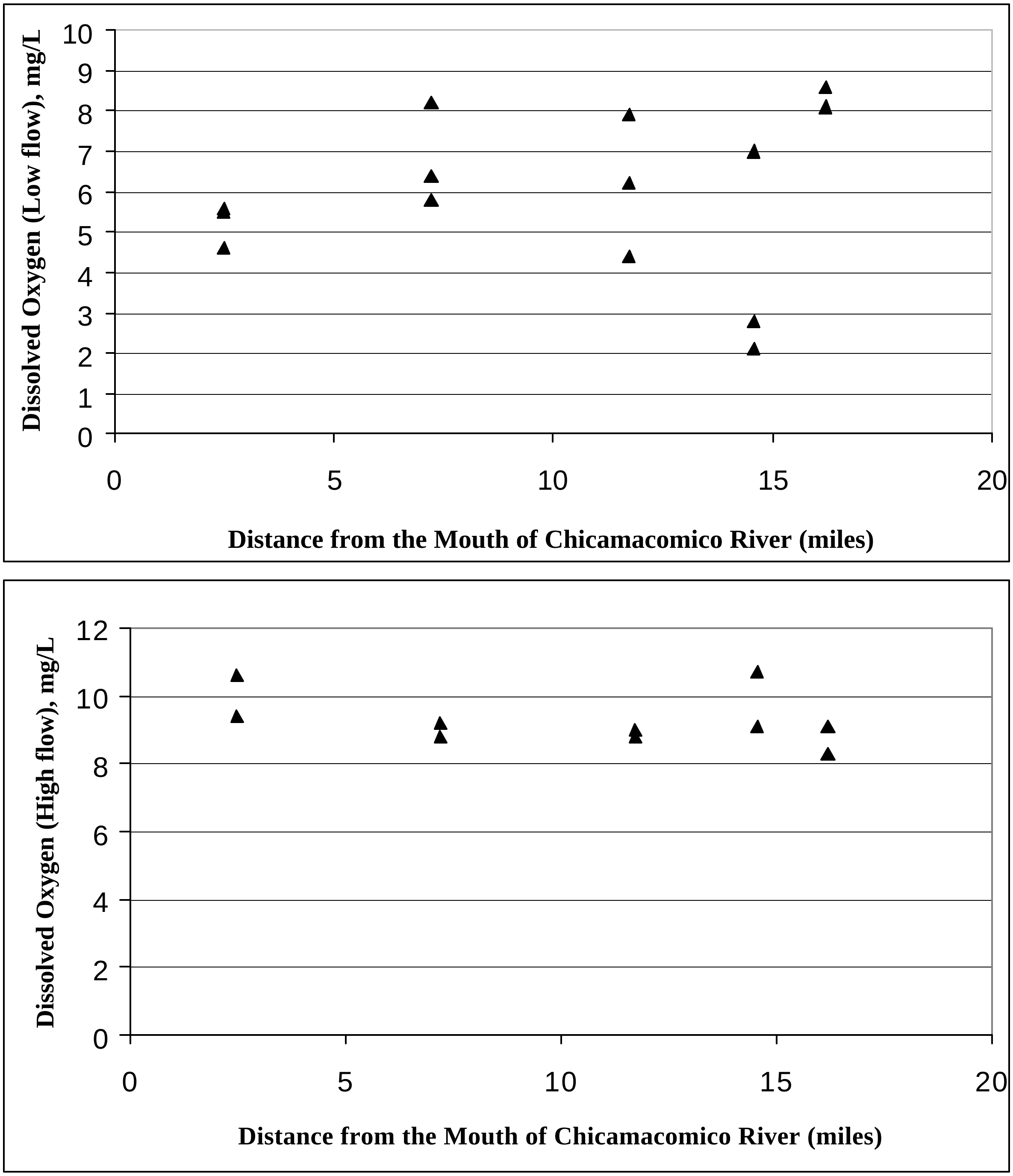

Figure A4: Longitudinal Profile of Dissolved Oxygen Data

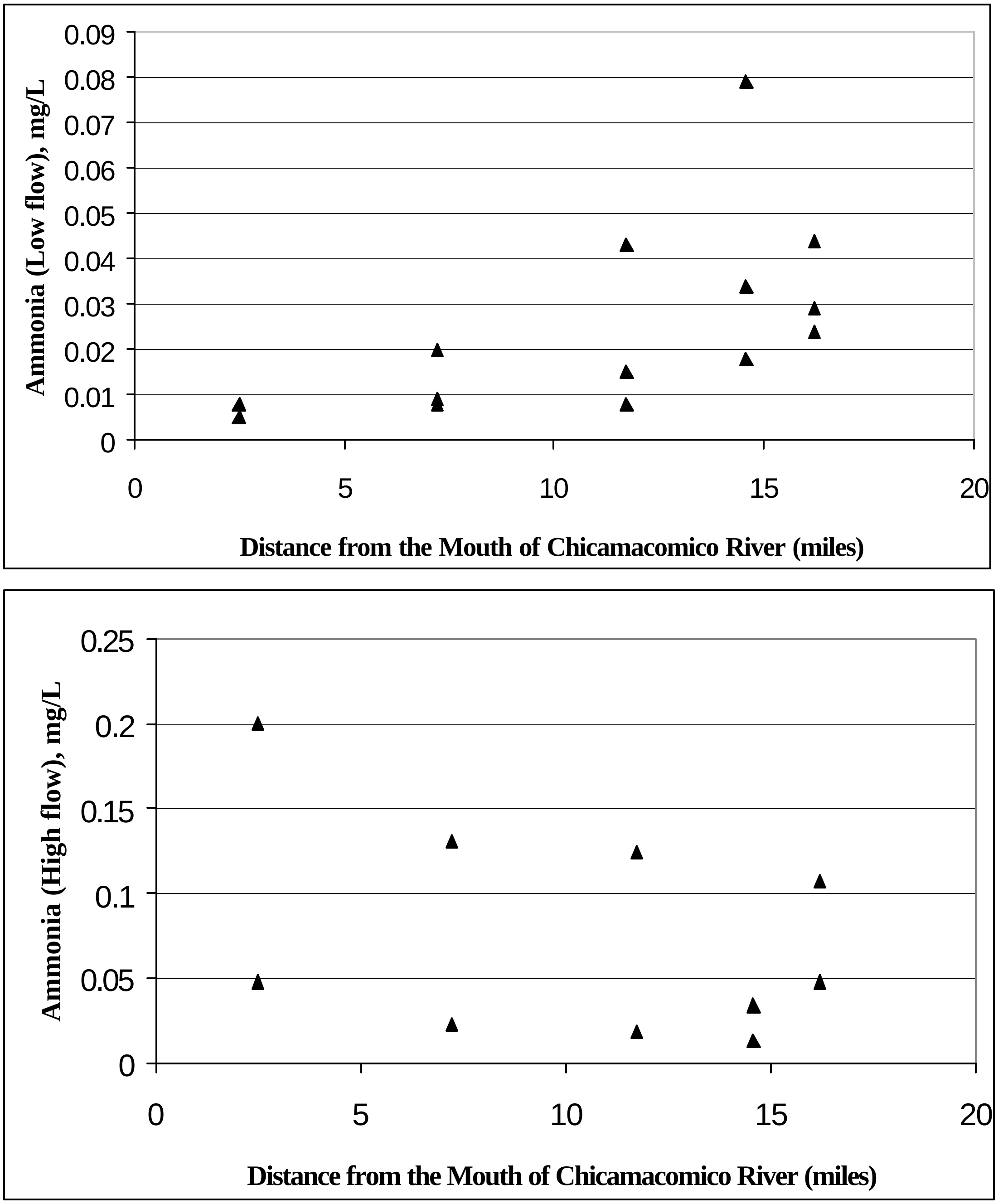

Figure A5: Longitudinal Profile of Ammonia Data

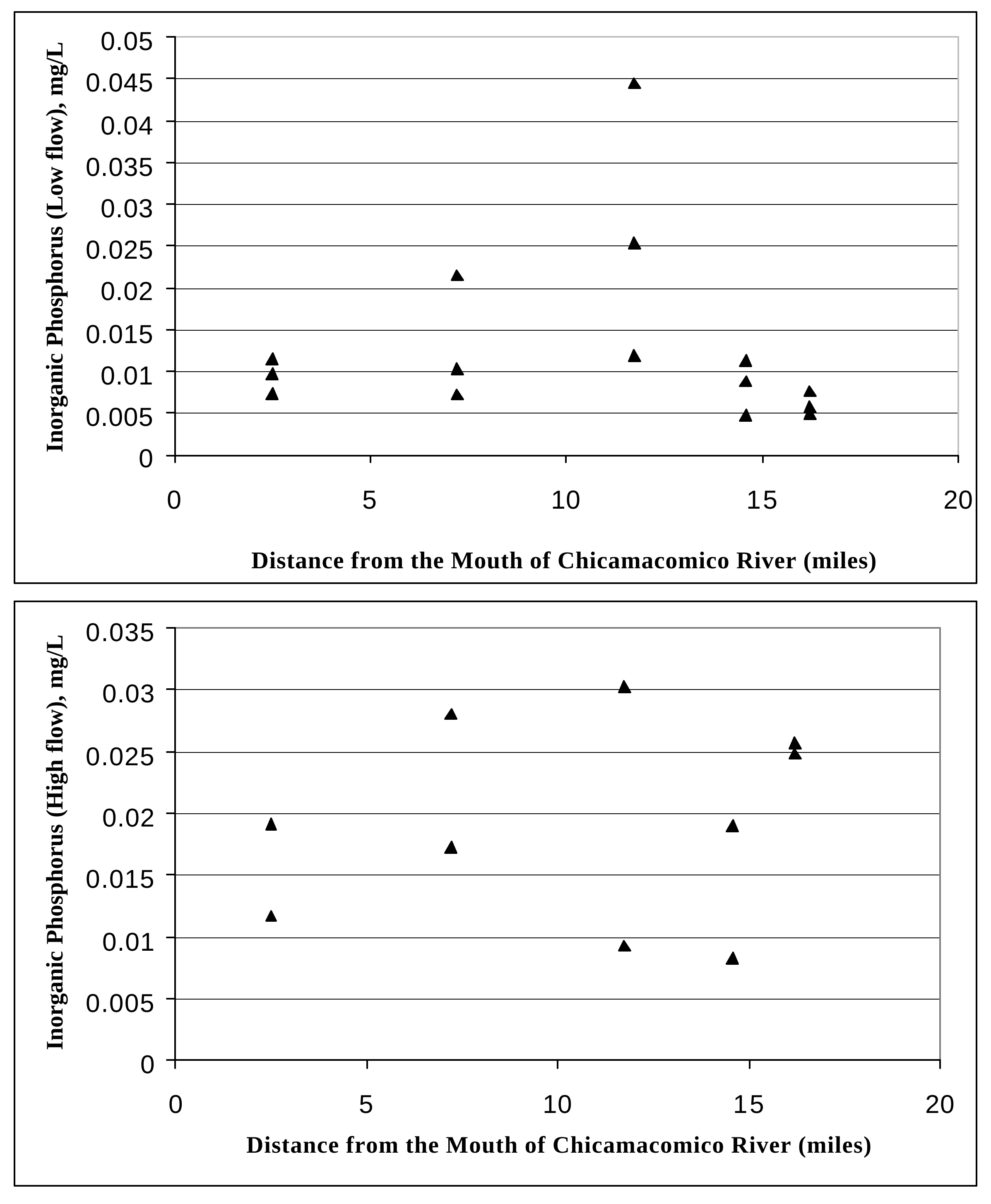

Figure A6: Longitudinal Profile of Inorganic Phosphorus Data

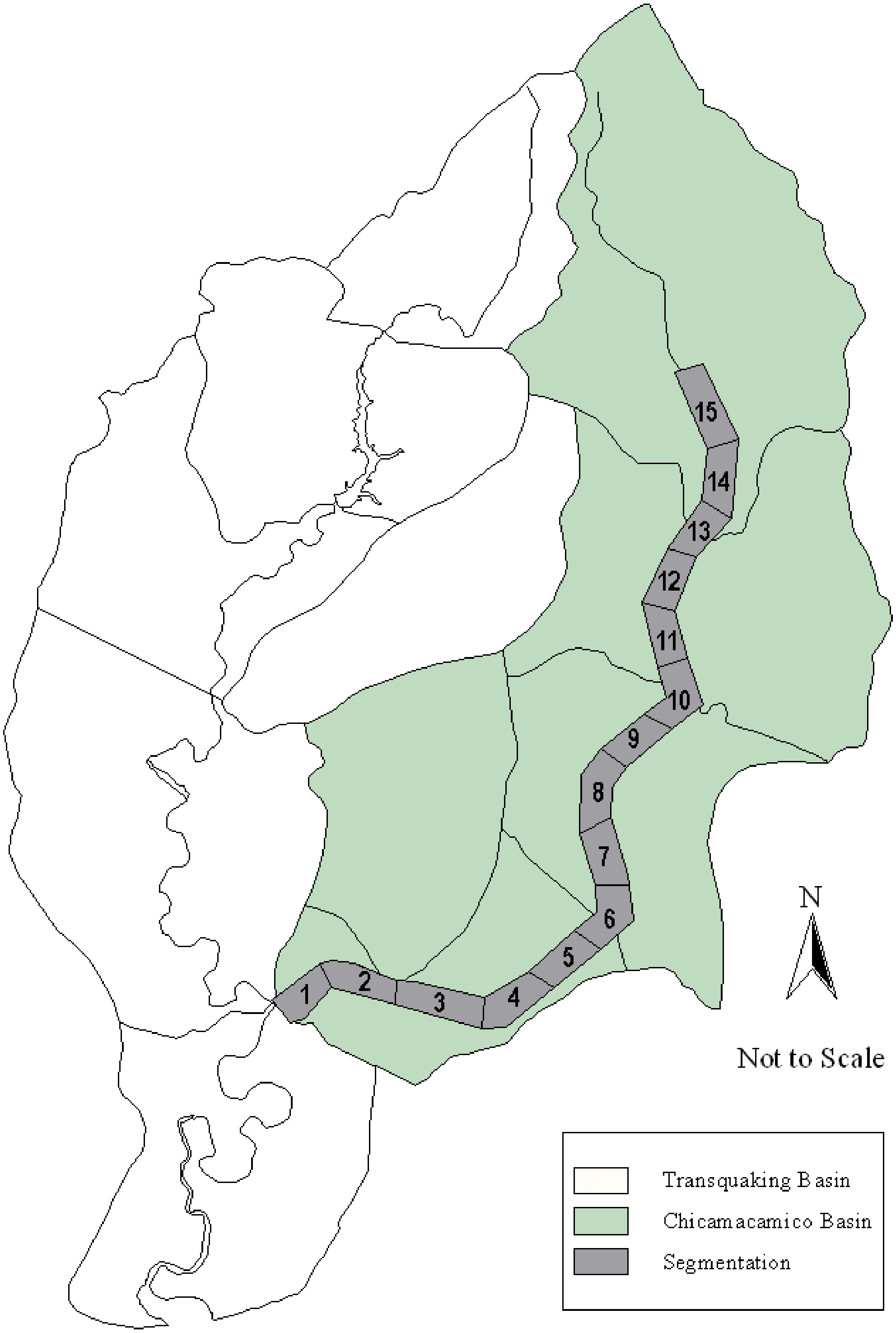

Figure A7: Model Segmentation, including Subwatersheds

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

Segment No.	Volume (m3)	Characteristic Length (m)	Interfacial Area (m2)
1	186004.5	2020	90.2
2	153815.3	2205	83.04
3	97018.9	2110	49.28
4	76998.2	2259	36.29
5	56147.9	2336	32.89
6	61921.1	2200	30.04
7	43914.1	2038	26.36
8	36216.5	2029	23.36
9	30558.7	2168	20.73
10	50231.6	2201	18.83
11	20007.7	2134	15.51
12	26547.5	2138	13.29
13	32484.8	2315	11.15
14	25986.7	1970	150
15	783.1	1794	0.5

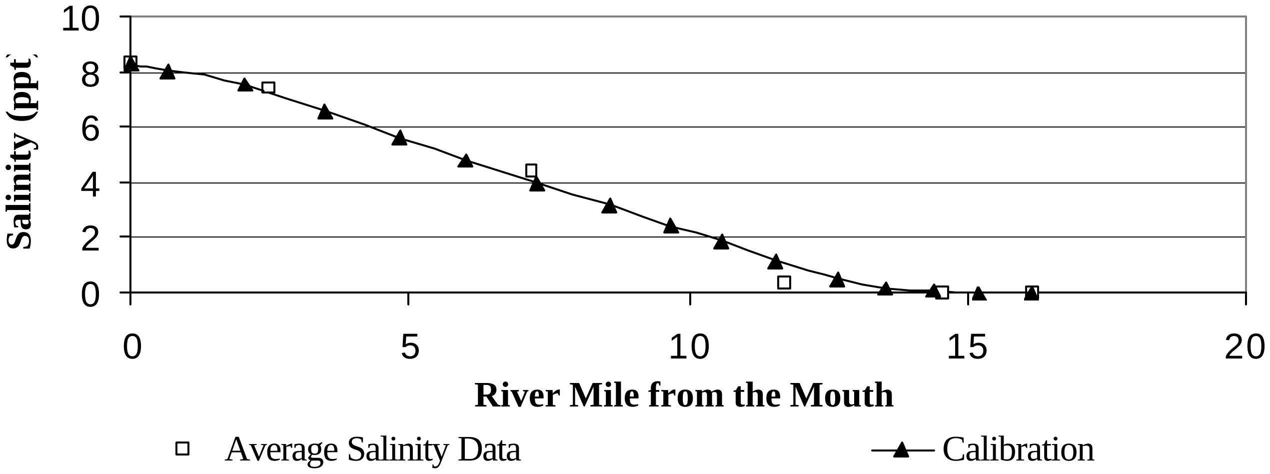

Figure A8: Results of the Calibration of Exchange Coefficients for Low Flow

Table A3: Dispersion Coefficients used in the CREM

Segment Nos.	Dispersion coefficients (m^2/sec)
1	100
2	85
3	70
4	60
5	60
6	55
7	50
8	40
9	35
10	20
11	10
12	10
13	5
14	0
15	0

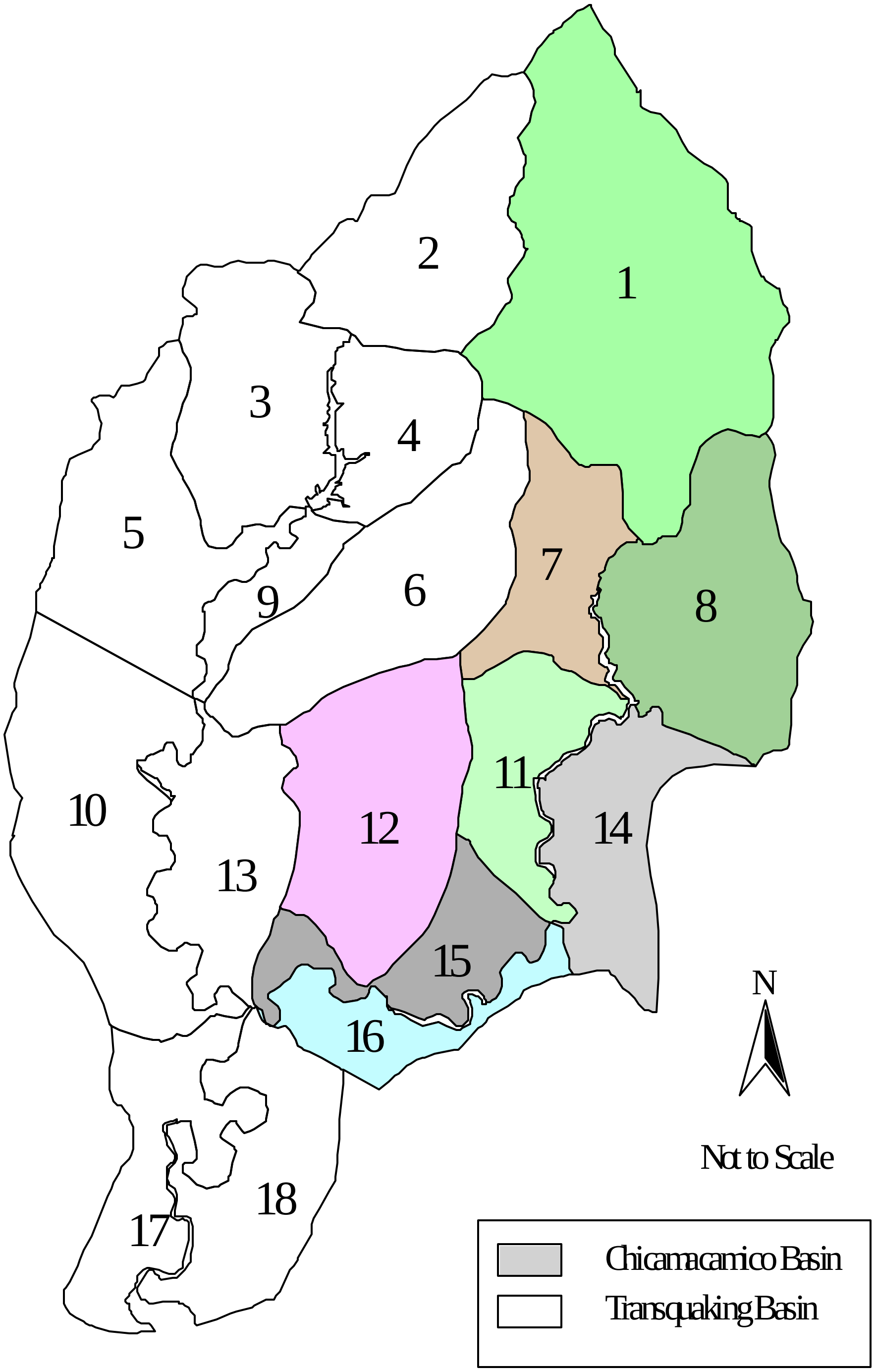

Figure A9: The Eighteen Subwatersheds of the Transquaking/Chicamacomico River Drainage Basin

Table A4: Subwatersheds flow for low, high, and average conditions

Subwatershed Nos.	Flow Symbols	Low flow (m^3/sec)	High flow (m^3/sec)	Average flow (m^3/sec)
1	Q_1	0.336	2.993	0.573
7	Q_7	0.055	0.734	0.141
8	Q_8	0.144	1.447	0.277
11	Q_{11}	0.054	0.720	0.138
12	Q_{12}	0.142	1.432	0.274
14	Q_{14}	0	0.902	0.173
15	Q_{15}	0	0.665	0.127
16	Q_{16}	0	0.484	0.093

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)		FNH4 (mg NH_4-N/m^2 day)		FPO4 (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	3.0	0	140	0	14
2	11.5	4.875	7.5	28.6	0.0	8.7	0.5	1.5	0	126	0	12.6
3	11.5	4.875	7.5	28.6	0.0	7.0	0.5	1.0	0	112	0	11.2
4	11.5	4.875	7.5	28.6	0.0	6.0	0.5	1.0	0	98	0	9.8
5	11.5	4.875	7.5	28.6	0.0	5.0	0.5	1.0	0	84	0	8.4
6	11.5	4.875	7.5	28.6	0.0	4.1	0.5	1.0	0	70	0	7
7	11.5	4.875	7.5	28.6	0.0	3.1	0.5	1.0	0	70	0	7
8	11.5	4.875	9.2	28.6	0.0	2.1	0.5	1.0	0	70	0	7
9	11.5	4.875	9.2	28.6	0.0	1.1	0.5	1.0	0	56	0	5.6
10	11.5	4.875	9.2	26.6	0.0	0.3	0.5	1.0	0	56	0	5.6
11	11.5	4.875	9.2	26.6	0.0	0.04	0.5	1.0	0	42	0	4.2
12	11.5	4.875	9.2	26.6	0.0	0.04	0.5	1.0	0	42	0	4.2
13	11.5	4.875	9.2	26.6	0.0	0.0	0.5	1.1	0	28	0	2.8
14	11.5	4.875	9.2	26.6	0.0	0.0	0.5	1.1	0	14	0	1.4
15	11.5	4.875	9.2	26.6	0.0	0.0	0.5	0.5	0	0	0	0

Table A6: EUTRO5 Kinetic Coefficients

Constant	Code	Value
Nitrification rate	K12C	0.15 *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	0.075 *day* -1 at 20° C
temperature coefficient	K1RT	1.08
Nonpredatory phytoplankton death rate	K1D	0.045 *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*-P/ mg C*
Half-saturation constants for phytoplankton growth		
Nitrogen	KMNG1	0.01 *mg* N / L
Phosphorus	KMPG1	0.01 *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	500. *Ly/day*
BOD deoxygenation rate	KDC	0.11 *day* -1 at 20° C
temperature coefficient	KDT	1.047
Half saturation const. for carb. deoxygenation	KBOD	0.0
Reaeration rate constant	k2	0.17 *day* -1 at 20° C
Mineralization rate of dissolved organic nitrogen	K71C	0.001 *day* -1
temperature coefficient	K71T	1.08
Mineralization rate of dissolved organic phosphorus	K58C	0.10 *day* -1
temperature coefficient	K58T	1.08
Phytoplankton settling velocity		0.086 *m/day*
Organics settling velocity		0.017 *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	Average flow m^3/sec
S1	15+16	0.0000	0.1148	0.0220
S2	15+16	0.0000	1.6195	0.0359
S3	15+16+12	0.0639	0.3596	0.3432
S4	15+16	0.0000	0.2478	0.0475
S5	15+16	0.0000	0.2387	0.0457
S6	11+14	0.0000	0.4326	0.0829
S7	11+14	0.0054	0.3963	0.0759
S8	11+14	0.0000	0.6305	0.1207
S9	11+14	0.0000	0.1622	0.0311
S10	7+8	0.0359	1.6691	0.3197
S12	7+8	0.0138	0.5116	0.0980
S13	1	0.0000	0.2993	0.0573
S14	1	0.0000	0.2993	0.0573
S15	1	0.1100	2.3942	0.4586

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	0.007	0.0061	0.0095	29.9705	4.9	5.03	1.5993	0.0400
3	0.0323	0.243	0.0092	0.4237	2.0	8.27	0.1305	0.0146
7	0.0323	0.243	0.0092	0.4237	2.0	8.27	0.1305	0.0146
10	0.0323	0.243	0.0092	0.4237	2.0	8.27	0.1305	0.0146
12	0.0323	0.243	0.0092	0.4237	2.0	8.27	0.1305	0.0146
15	0.0323	2.6133	0.0092	0.4237	2.0	8.27	0.1305	0.0146

Table A9: 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	0.124	0.571	0.0154	2.8145	2.0	10.01	0.6709	0.0497
2	0.0775	0.1067	0.0253	1.3083	2.0	8.7	0.5253	0.0245
3	0.0775	0.1067	0.0253	1.3083	2.0	8.7	0.5253	0.0245
4	0.0775	0.1067	0.0253	1.3083	2.0	8.7		
5	0.0775	0.1067	0.0253	1.3083	2.0	8.7	0.5253	0.0245
6	0.0775	0.1067	0.0253	1.3083	2.0	8.7	0.5253	0.0245
7	0.0775	0.1067	0.0253	1.3083	2.0	8.7	0.5253	0.0245
8	0.0775	0.1067	0.0253	1.3083	2.0	8.7		
9	0.0775	0.1067	0.0253	1.3083	2.0	8.7	0.5253	0.0245
10	0.0775	0.1067	0.0253	1.3083	2.0	8.7	0.5253	0.0245
12	0.0775	0.1067	0.0253	1.3083	2.0	8.7	0.5253	0.0245
13	0.0775	0.1067	0.0253	1.3083	2.0	8.7	0.5253	0.0245
14	0.0775	0.1067	0.0253	1.3083	2.0	8.7	0.5253	0.0245
15	0.0775	0.1067	0.0253	1.3083	2.0	8.7	0.923	0.0479

Low Flow Calibration

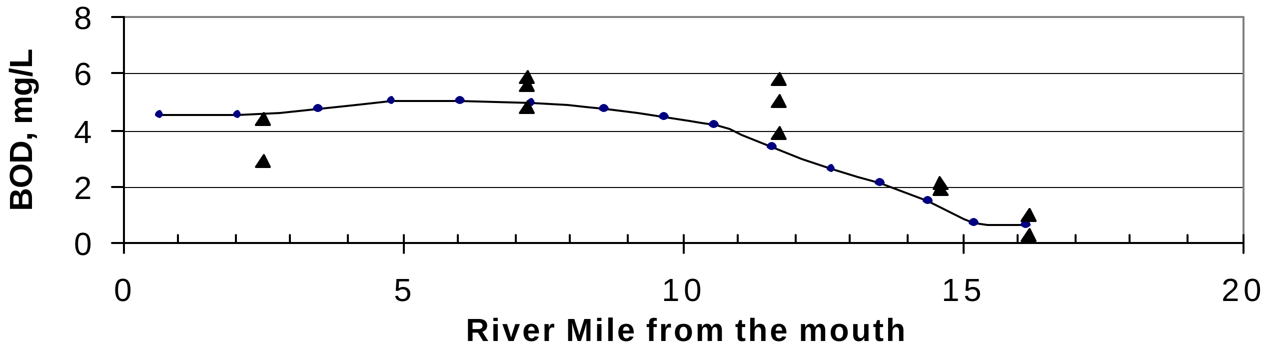

Figure A10: BOD vs. River Mile for the Calibration of the Model (Low flow)

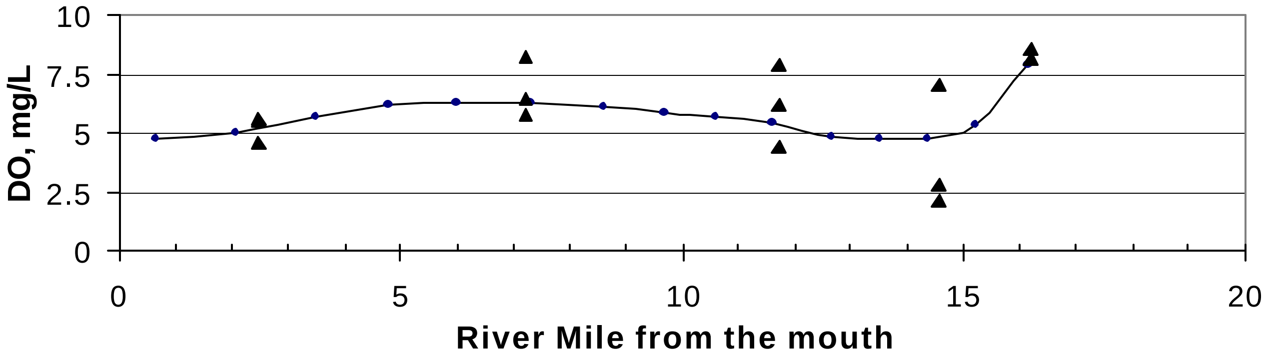

Figure A11: Dissolved Oxygen vs. River Mile for the Calibration of the Model (Low flow)

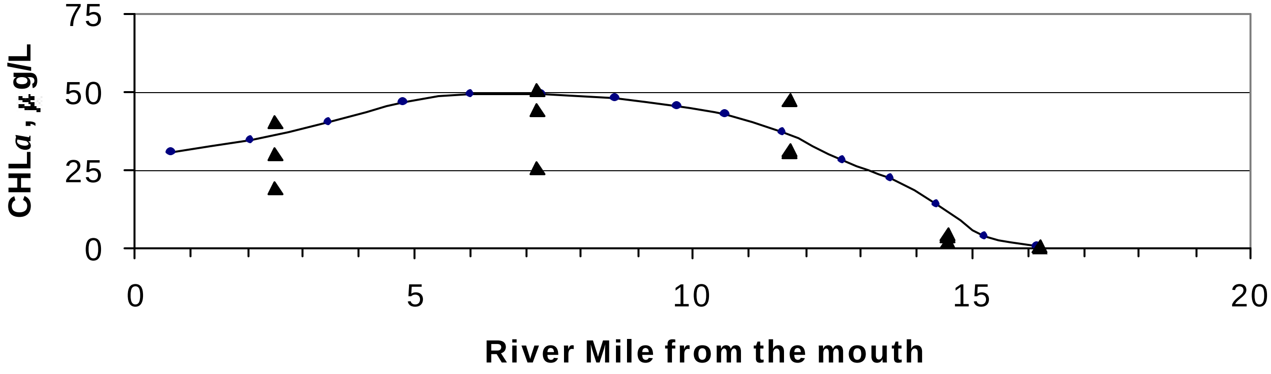

Figure A12: Chlorophyll *a* vs. River Mile for the Calibration of the Model (Low flow)

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

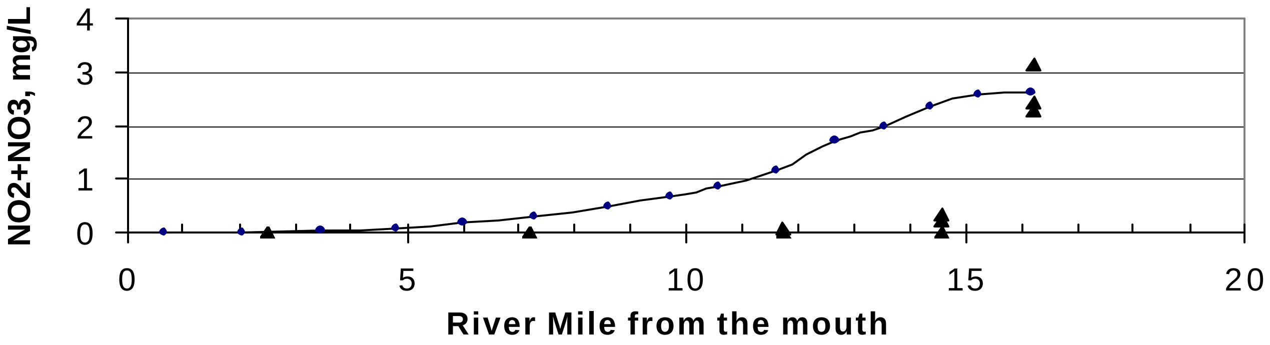

Figure A13: Nitrate (plus Nitrite) vs. River Mile for the Calibration of the Model (Low flow)

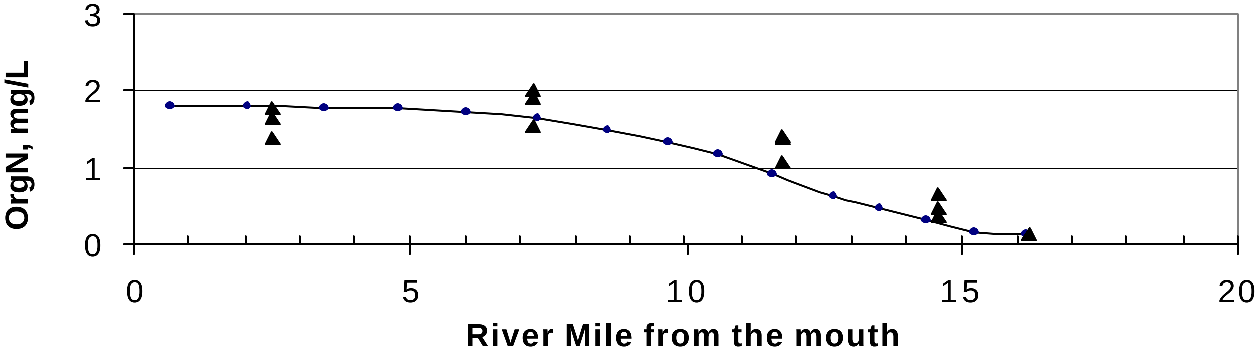

Figure A14: Organic Nitrogen vs. River Mile for the Calibration of the Model (Low flow)

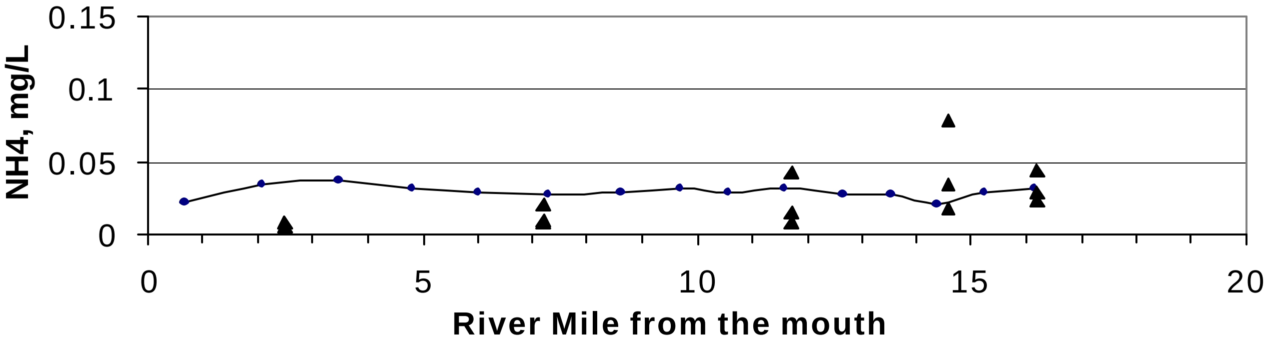

Figure A15: Ammonia vs. River Mile for the Calibration of the Model (Low flow)

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

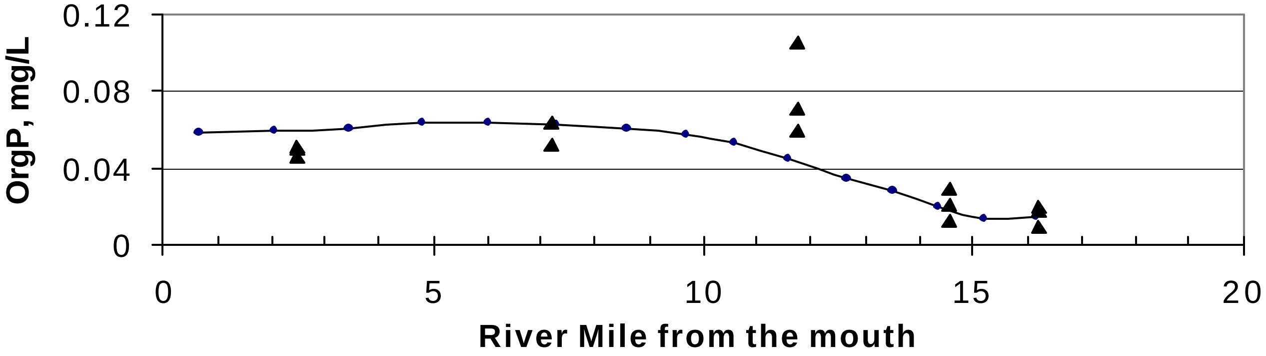

Figure A16: Organic Phosphorus vs. River Mile for the Calibration of the Model (Low flow)

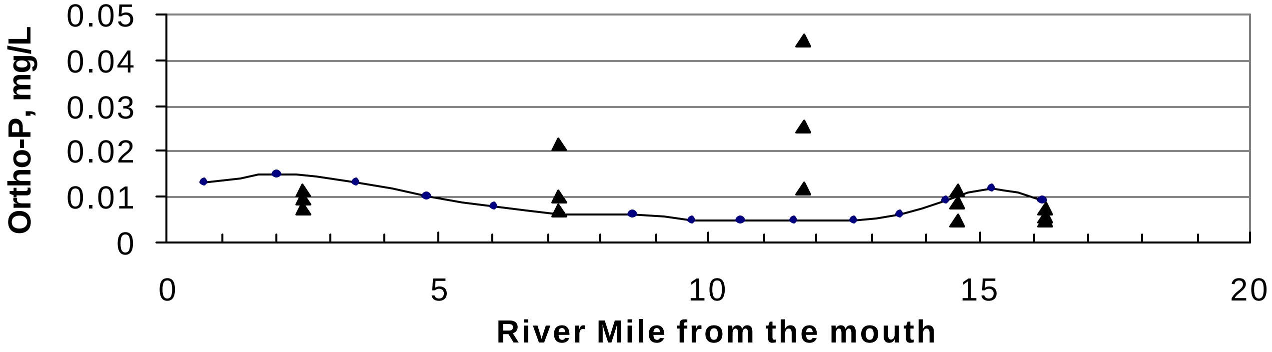

Figure A17: Ortho-Phosphate vs. River Mile for the Calibration of the Model (Low flow)

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

High Flow Calibration

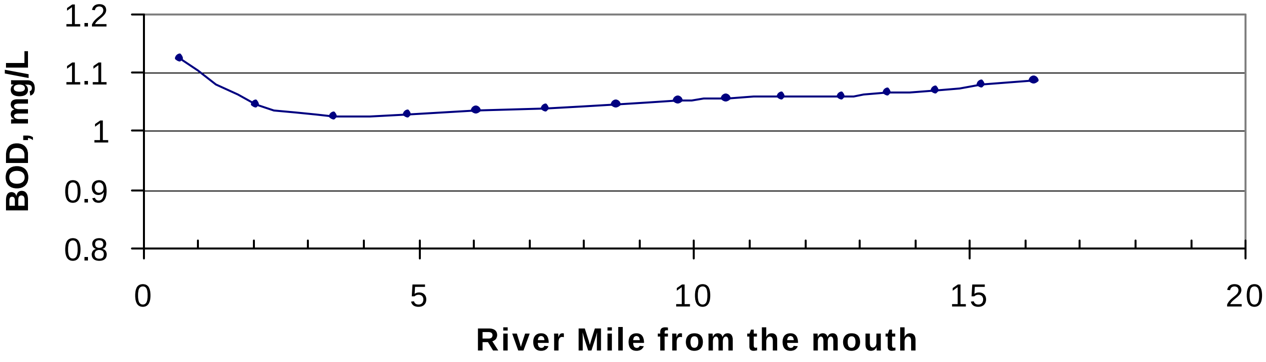

Figure A18: BOD vs. River Mile for the Calibration of the Model (High flow)

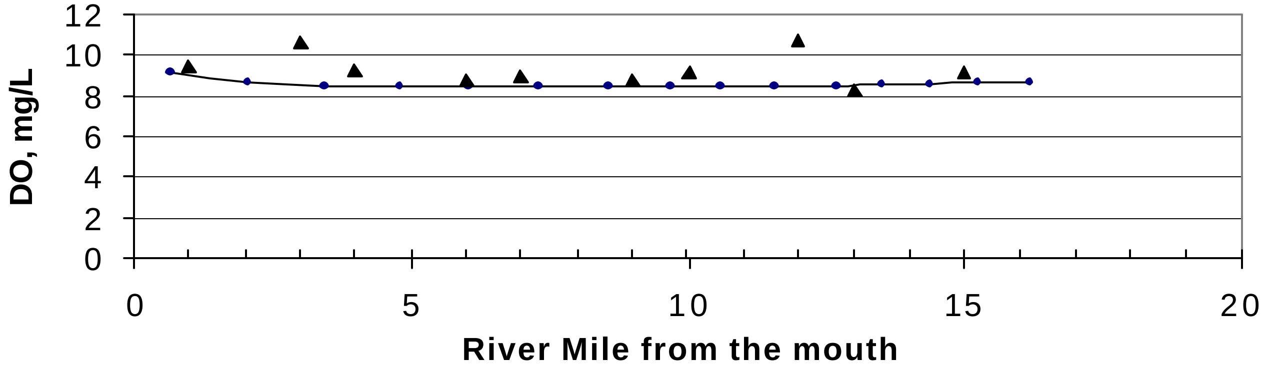

Figure A19: Dissolved Oxygen vs. River Mile for the Calibration of the Model (High Flow)

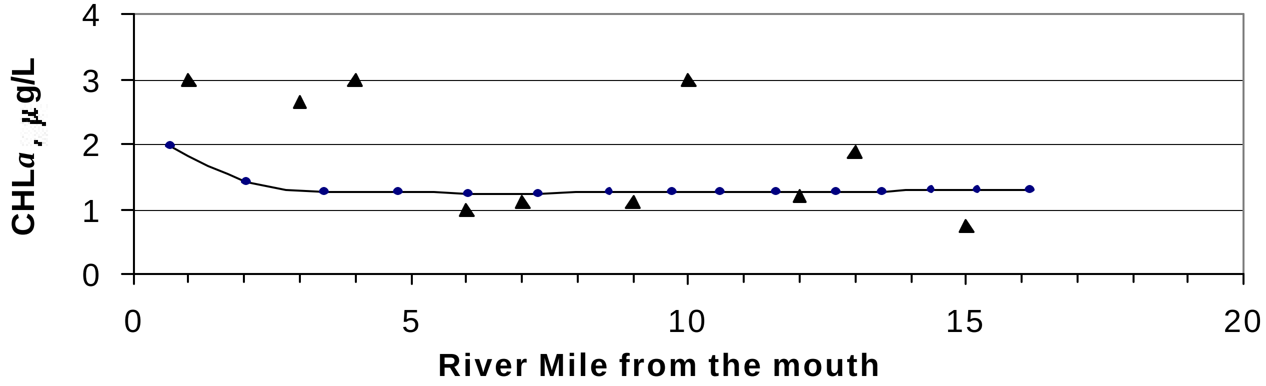

Figure A20: Chlorophyll *a* vs. River Mile for the Calibration of the Model (High flow)

▲ Monitoring Data **___ Calibration**

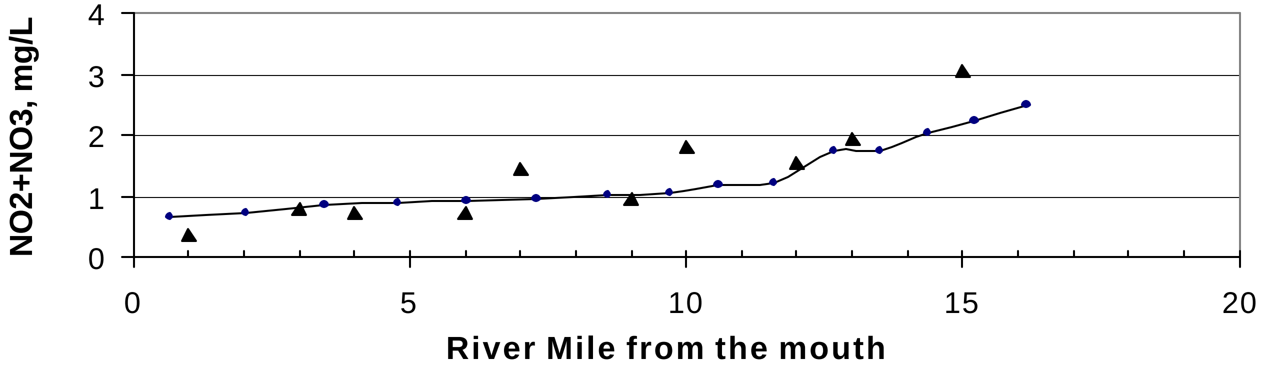

Figure A21: Nitrate (plus Nitrite) vs. River Mile for the Calibration of the Model (High flow)

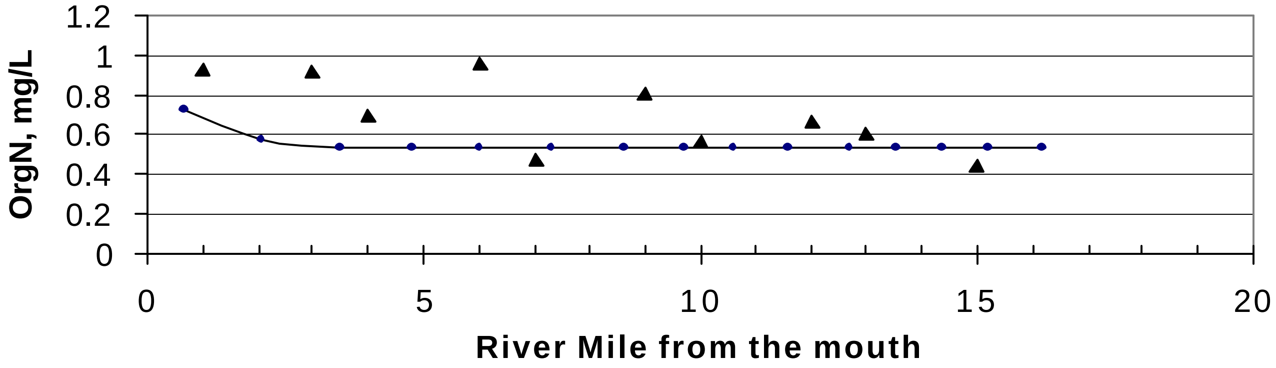

Figure A22: Organic Nitrogen vs. River Mile for the Calibration of the Model (High flow)

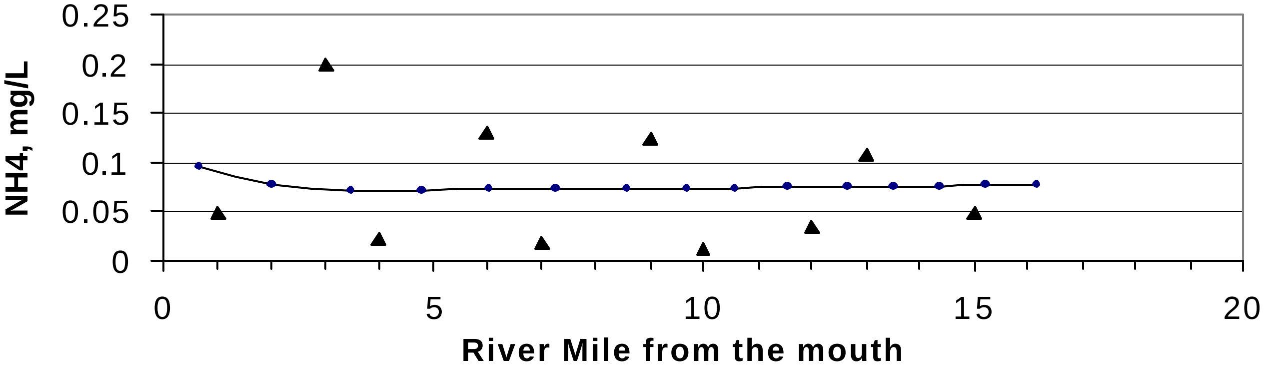

Figure A23: Ammonia vs. River Mile for the Calibration of the Model (High flow)

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

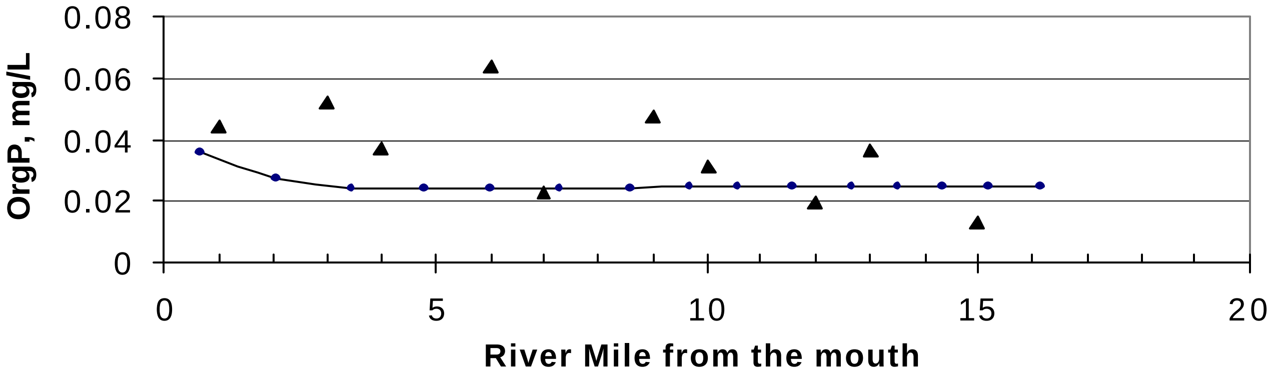

Figure A24: Organic Phosphorus vs. River Mile for the Calibration of the Model (High flow)

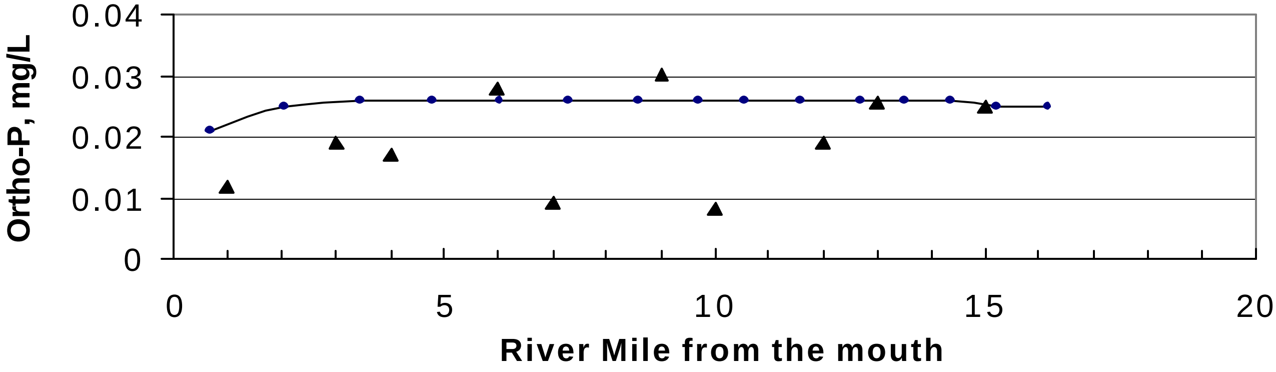

Figure A25: Ortho-Phosphate vs. River Mile for the Calibration of the Model (High flow)

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

Table A10: 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	0.007	0.0061	0.0095	29.9705	4.9	5.03	1.5993	0.0400
3	0.0323	0.243	0.0092	0.4237	2.0	8.27	0.1305	0.0146
7	0.0323	0.243	0.0092	0.4237	2.0	8.27	0.1305	0.0146
10	0.0323	0.243	0.0092	0.4237	2.0	8.27	0.1305	0.0146
12	0.0323	0.243	0.0092	0.4237	2.0	8.27	0.1305	0.0146
15	0.0323	2.6133	0.0092	0.4237	2.0	8.27	0.1305	0.0146

Table A11: Nonpoint Source Concentrations for the Base-line Average Flow Condition

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	0.007	0.0061	0.0095	29.97	4.9	5.22	1.5993	0.0400
2	0.1687	0.7090	0.0402	0.42	3.33	8.27	0.8563	0.0878
3	0.2008	0.9468	0.0417	0.42	3.33	8.27	0.7697	0.0843
4	0.1905	0.7667	0.0375	0.42	3.33	8.27	0.7865	0.0848
5	0.1938	0.8239	0.0388	0.42	3.33	8.27	0.7812	0.0847
6	0.0357	0.2167	0.0098	0.42	3.33	8.27	0.1526	0.0166
7	0.1168	0.7099	0.0322	0.42	3.33	8.27	0.4999	0.0544
8	0.1224	0.7438	0.0337	0.42	3.33	8.27	0.5238	0.0570
9	0.1764	1.0190	0.0468	0.42	3.33	8.27	0.8005	0.0823
10	0.2240	0.9855	0.0559	0.42	3.33	8.27	1.0716	0.1184
12	0.2428	1.1492	0.0625	0.42	3.33	8.27	1.1272	0.1266
13	0.2190	0.8530	0.0567	0.42	3.33	8.27	1.1174	0.1223
14	0.2190	0.8530	0.0567	0.42	3.33	8.27	1.1174	0.1223
15	0.2190	0.8530	0.0567	0.42	4.90	8.27	1.1174	0.1223

Base-line Low Flow Scenario

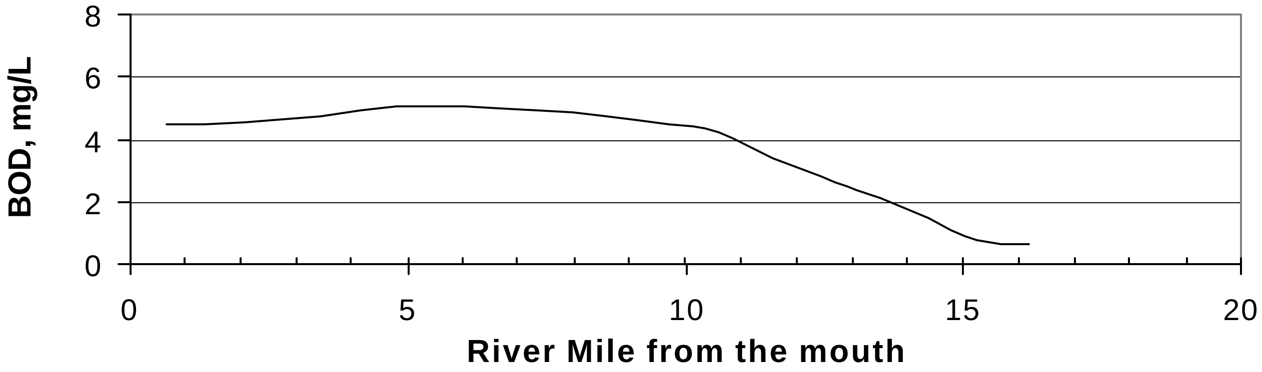

Figure A26: BOD vs. River Mile for the Base-line Low Flow Scenario

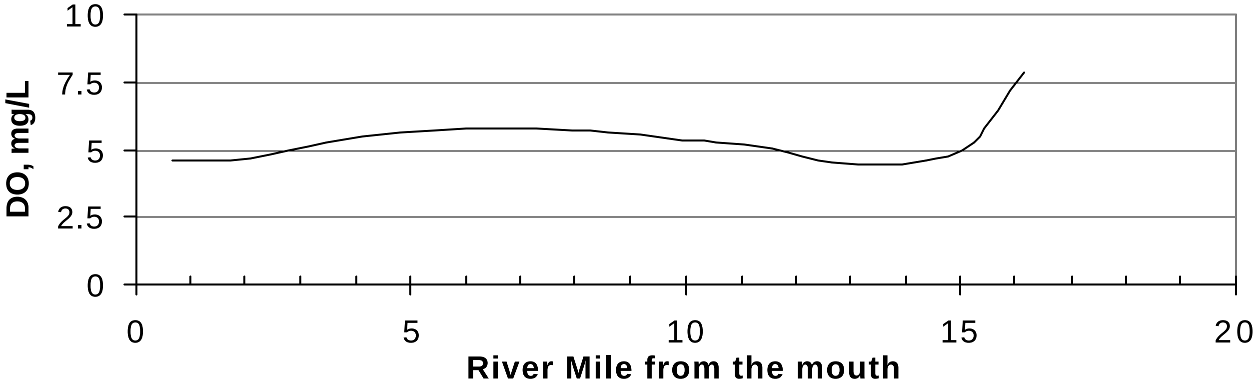

Figure A27: Dissolved Oxygen vs. River Mile for the Base-line Low Flow Scenario

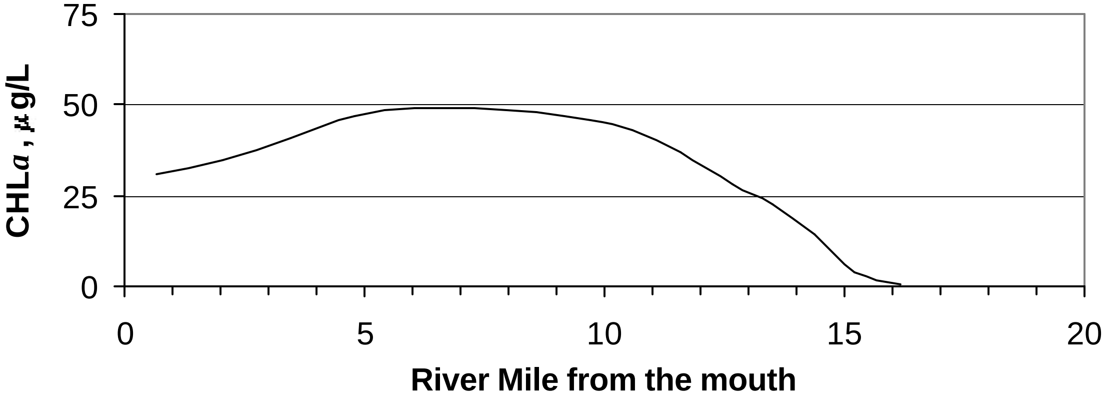

Figure A28: Chlorophyll *a* vs. River Mile for the Base-line Low Flow Scenario

_____ Base-line low flow condition

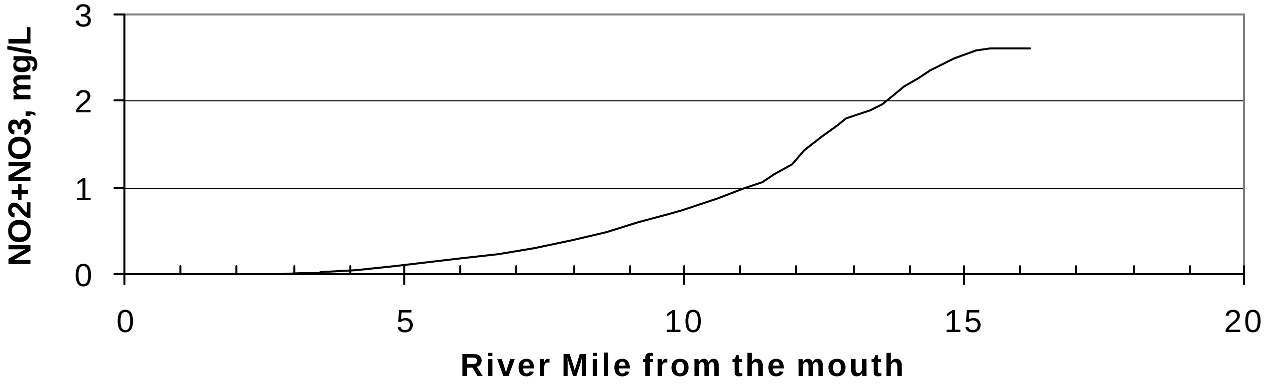

Figure A29: Nitrate (plus Nitrite) vs. River Mile for the Base-line Low Flow Scenario

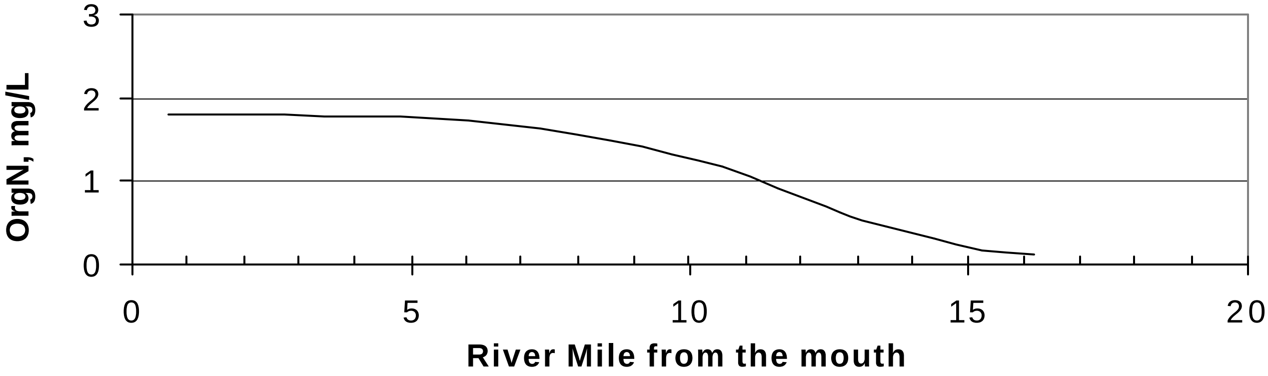

Figure A30: Organic Nitrogen vs. River Mile for the Base-line Low Flow Scenario

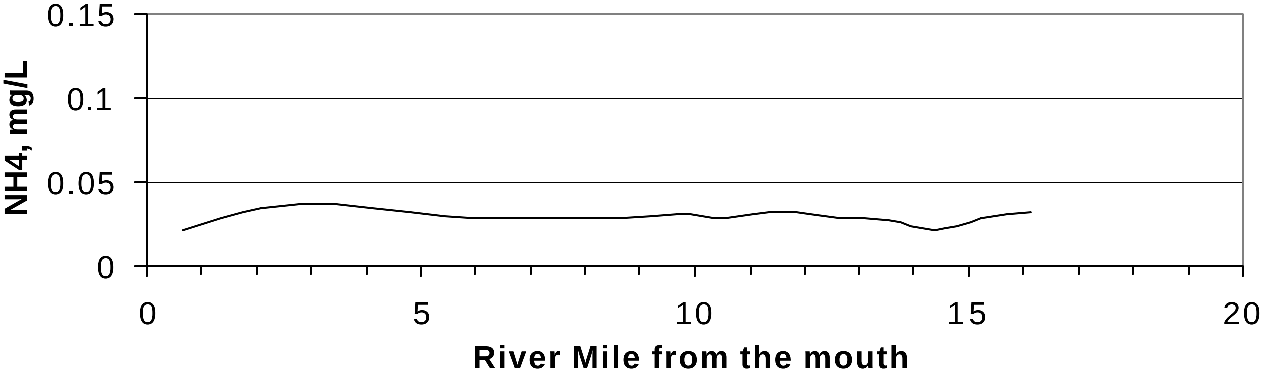

Figure A31: Ammonia vs. River Mile for the Base-line Low Flow Scenario

_____ **Base-line low flow condition**

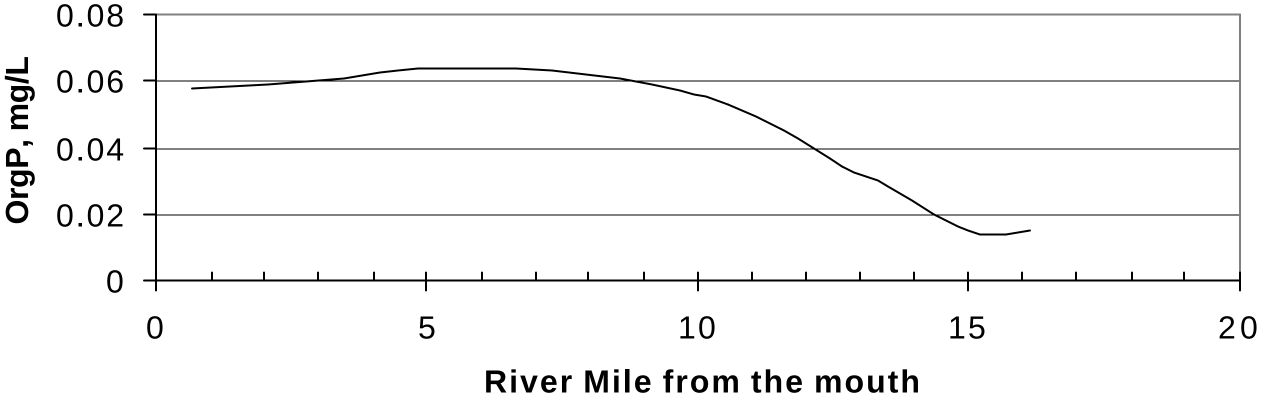

Figure A32: Organic Phosphorus vs. River Mile for the Base-line Low Flow Scenario

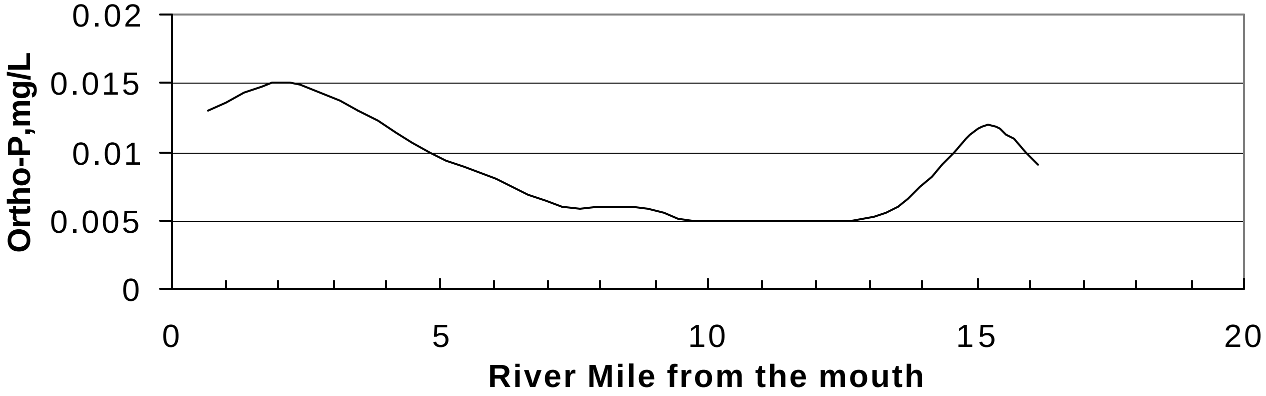

Figure A33: Ortho-Phosphorus vs. River Mile for the Base-line Low Flow Scenario

_____ Base-line low flow condition

Base-line Average Flow Scenario

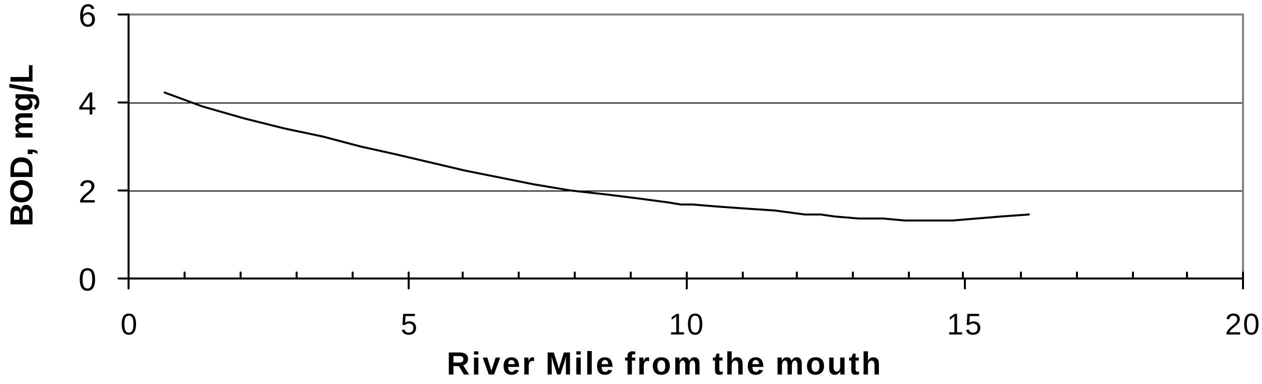

Figure A34: BOD vs. River Mile for the Base-line Average Flow Scenario

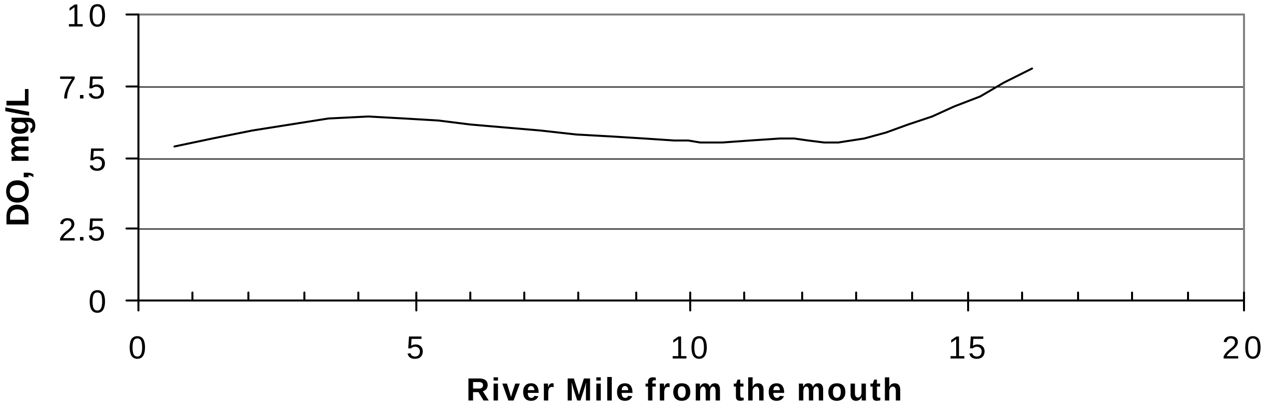

Figure A35: Dissolved Oxygen vs. River Mile for the Base-line Average Flow Scenario

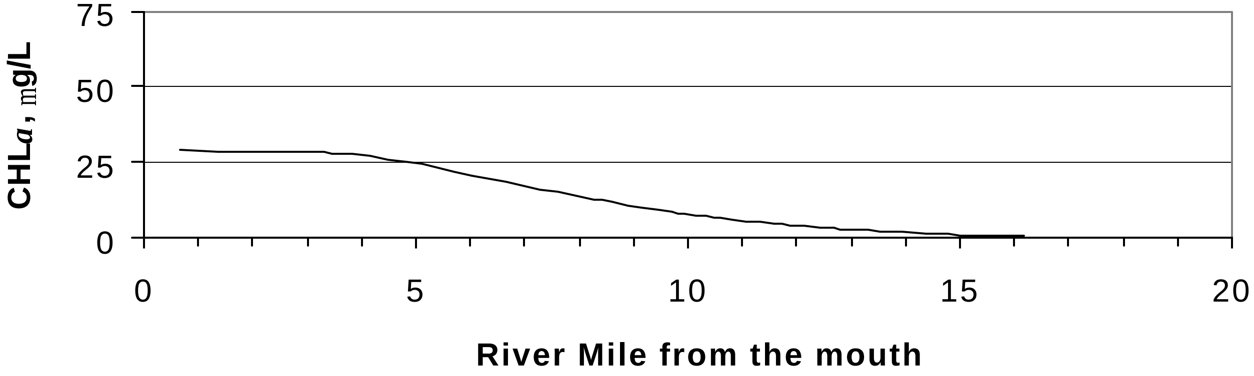

Figure A36: Chlorophyll *a* vs. River Mile for the Base-line Average Flow Scenario

—— **Base-line average flow condition**

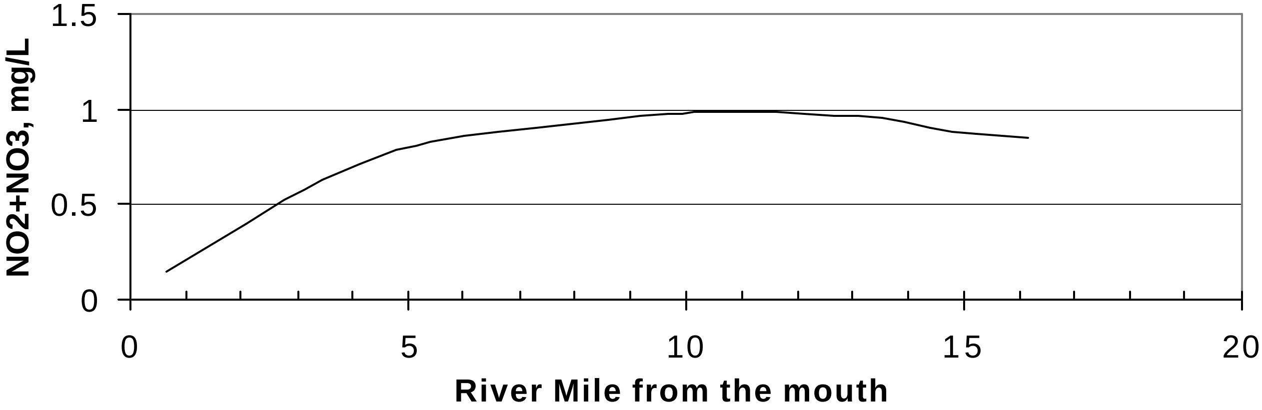

Figure A37: Nitrate (plus Nitrite) vs. River Mile for the Base-line Average Flow Scenario

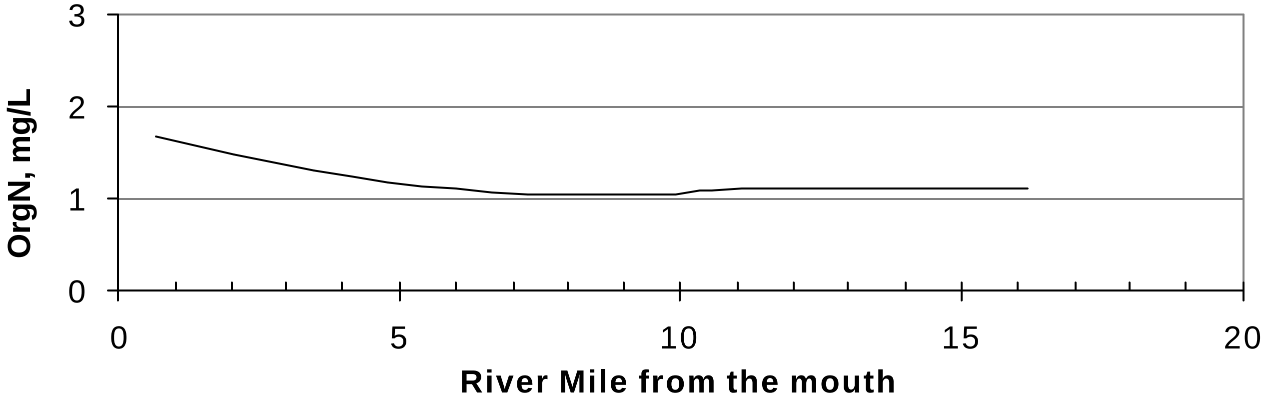

Figure A38: Organic Nitrogen vs. River Mile for the Base-line Average Flow Scenario

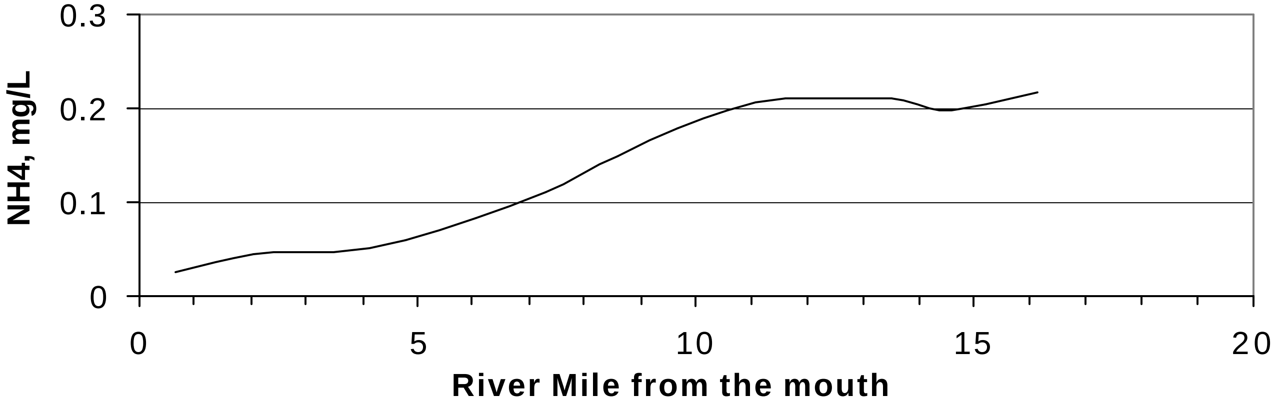

Figure A39: Ammonia vs. River Mile for the Base-line Average Flow Scenario

—— **Base-line average flow condition**

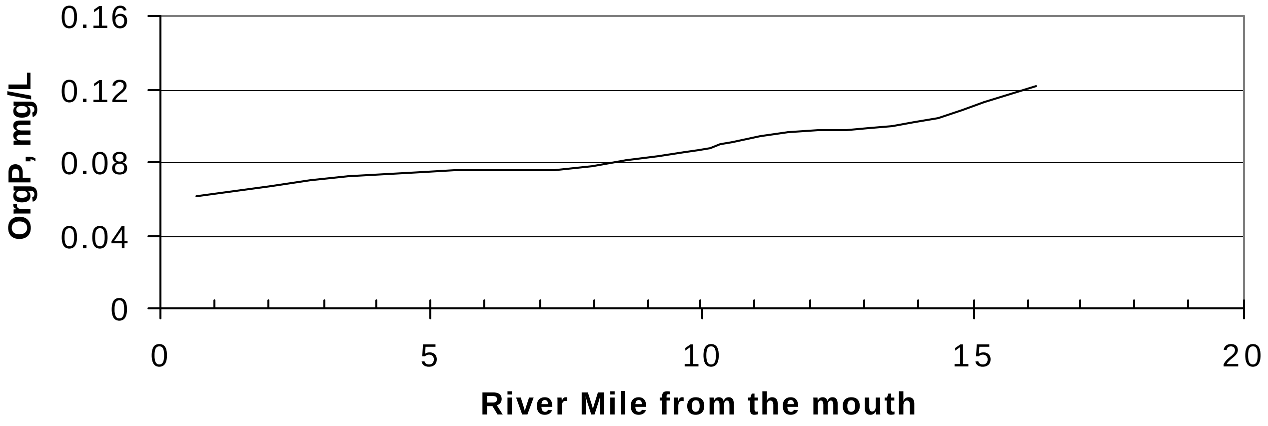

Figure A40: Organic Phosphorus vs. River Mile for the Base-line Average Flow Scenario

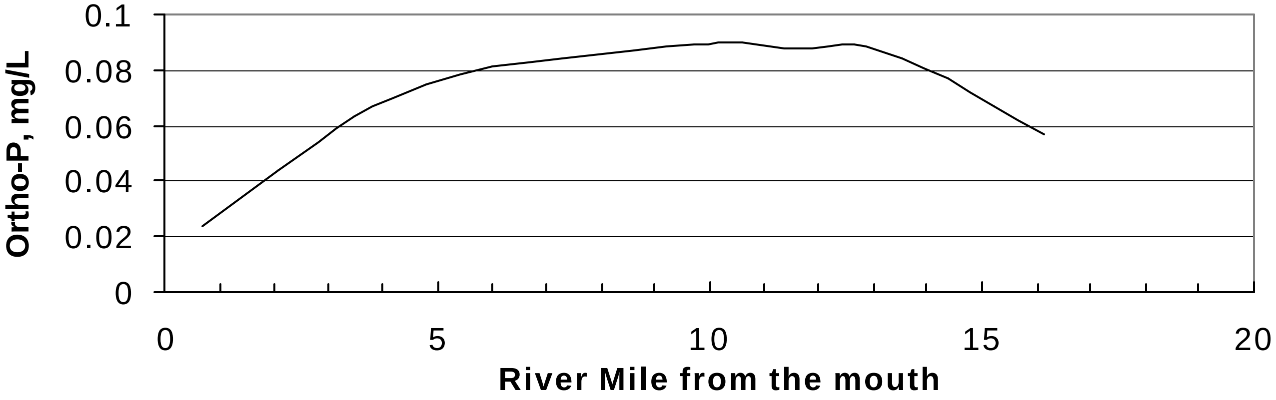

Figure A41: Ortho-Phosphorus vs. River Mile for the Base-line Average Flow Scenario

———— Base-line average flow condition

Future Low Flow TMDL Scenario Results

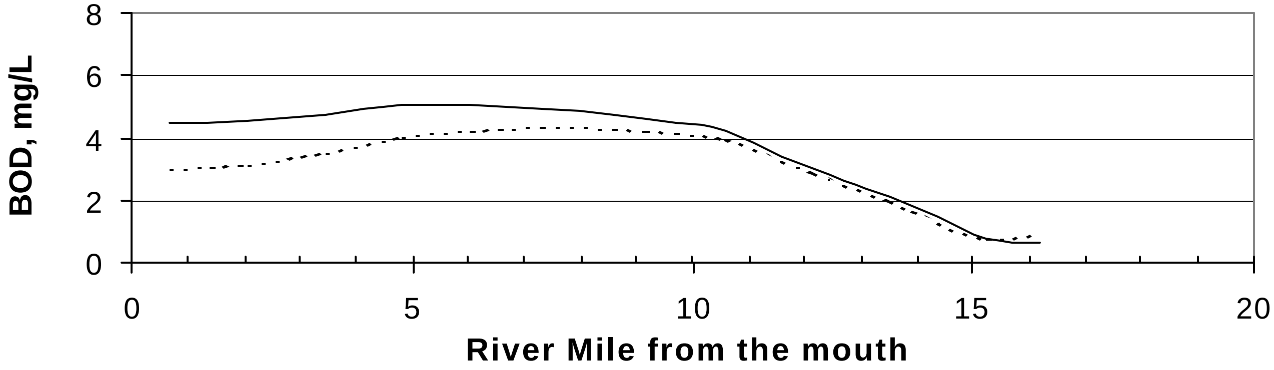

Figure A42: BOD vs. River Mile for the Future Low flow TMDL scenario

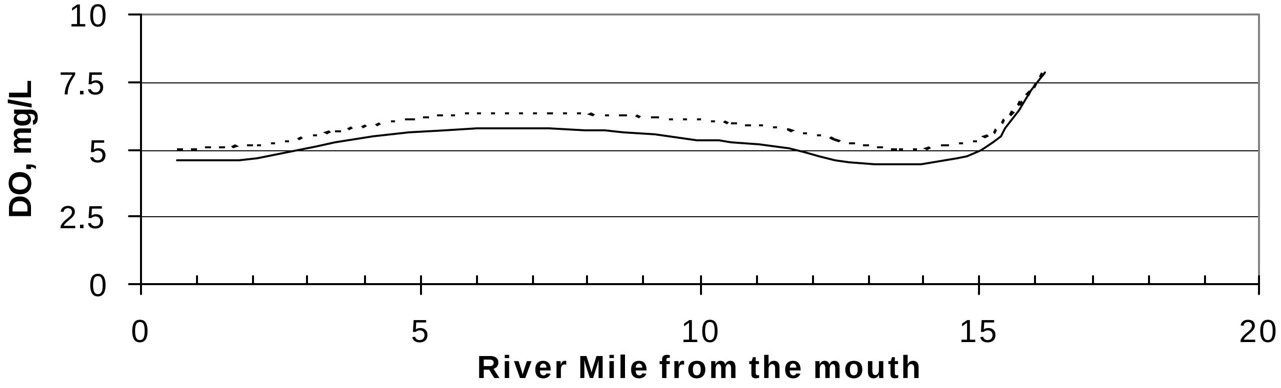

Figure A43: Dissolved Oxygen vs. River Mile for the Future Low Flow TMDL Scenario

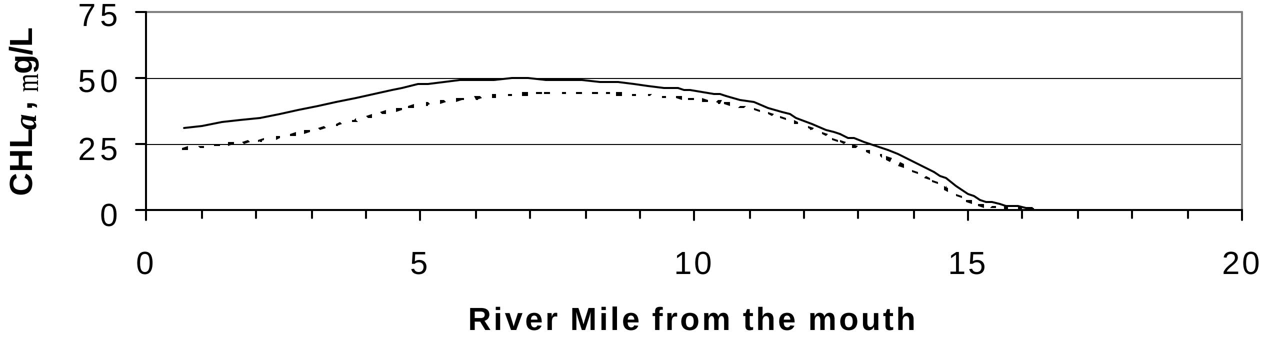

Figure A44: Chlorophyll *a* vs. River Mile for the Future Low Flow TMDL scenario

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

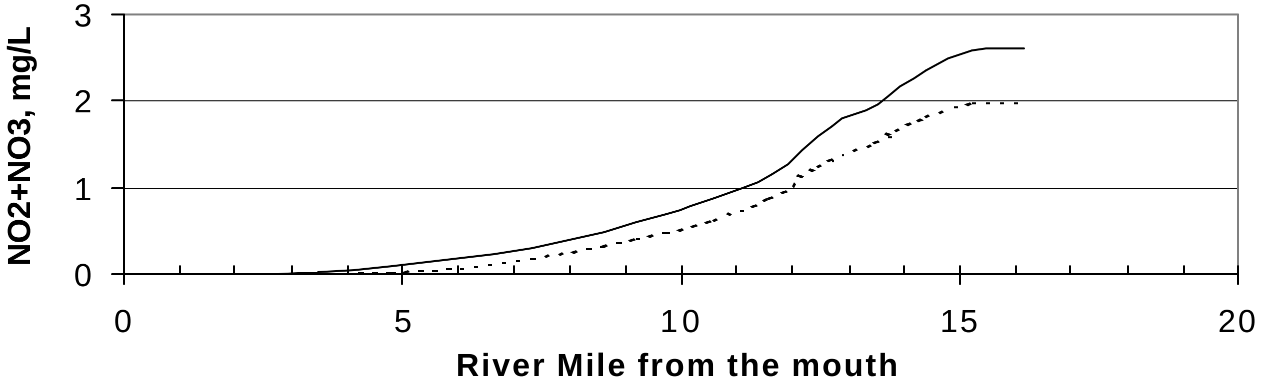

Figure A45: Nitrate (plus Nitrite) vs. River Mile for the Future Low flow TMDL Scenario

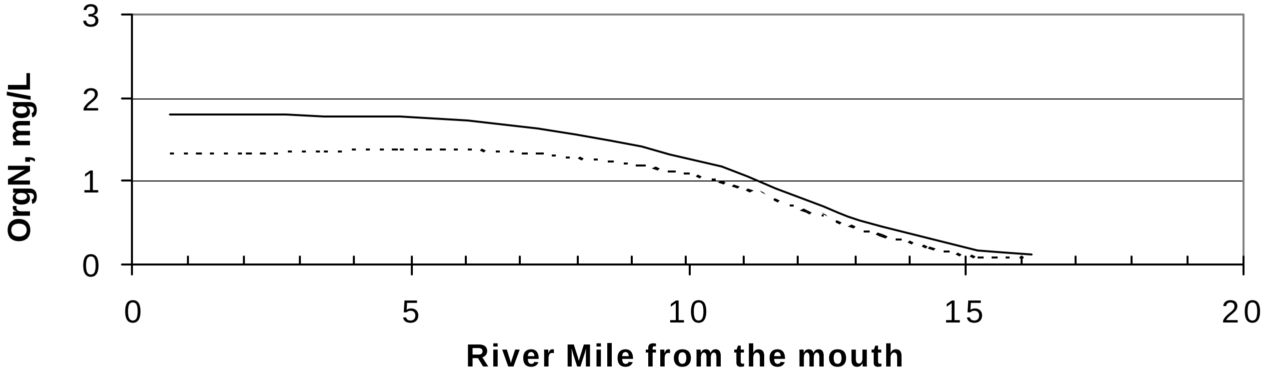

Figure A46: Organic Nitrogen vs. River Mile for the Future Low Flow TMDL Scenario

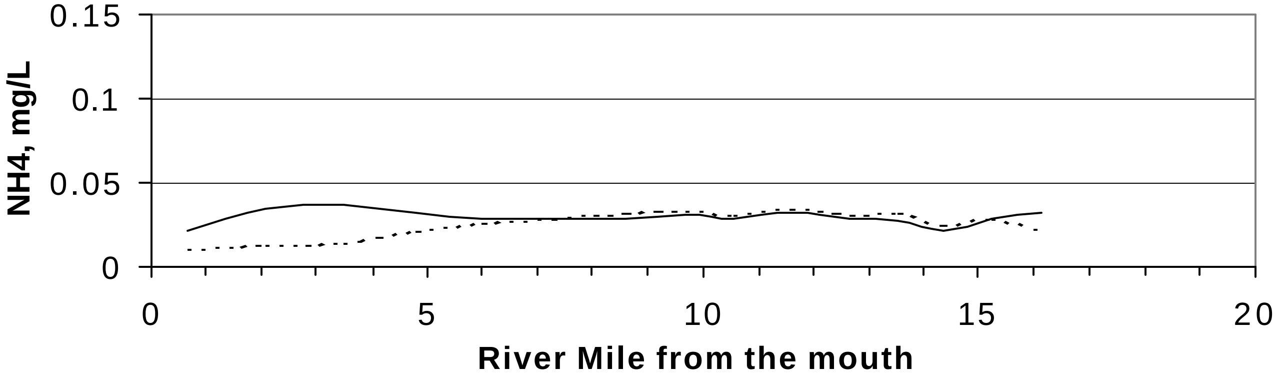

Figure A47: Ammonia vs. River Mile for the Future Low Flow TMDL Scenario

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

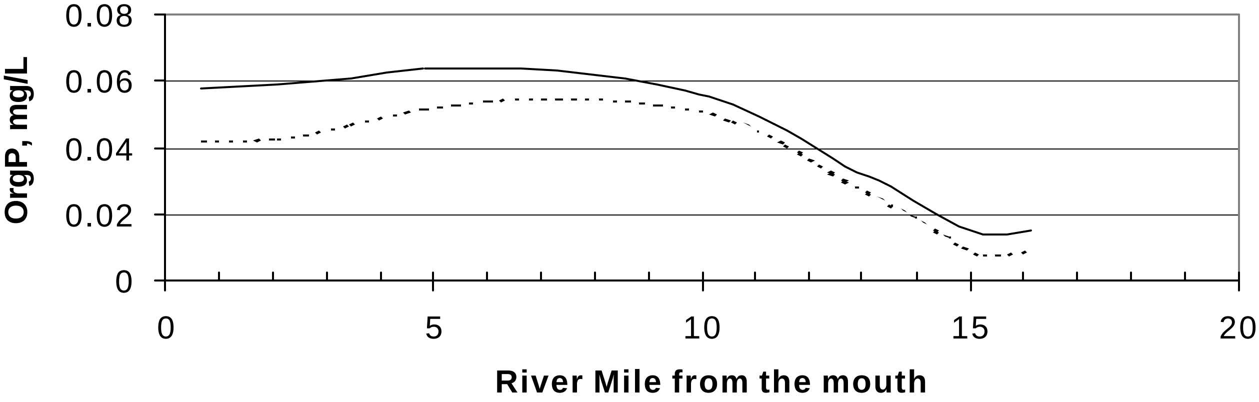

Figure A48: Organic Phosphorus vs. River Mile for the Future Low Flow TMDL Scenario

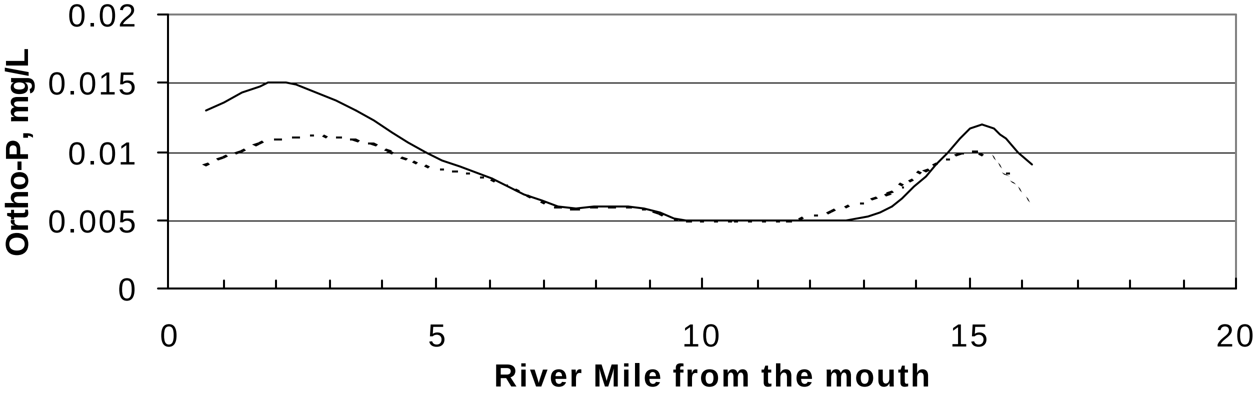

Figure A49: Ortho-Phosphate vs. River Mile for the Future Low Flow TMDL Scenario

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

Future Average Flow TMDL Scenario Results

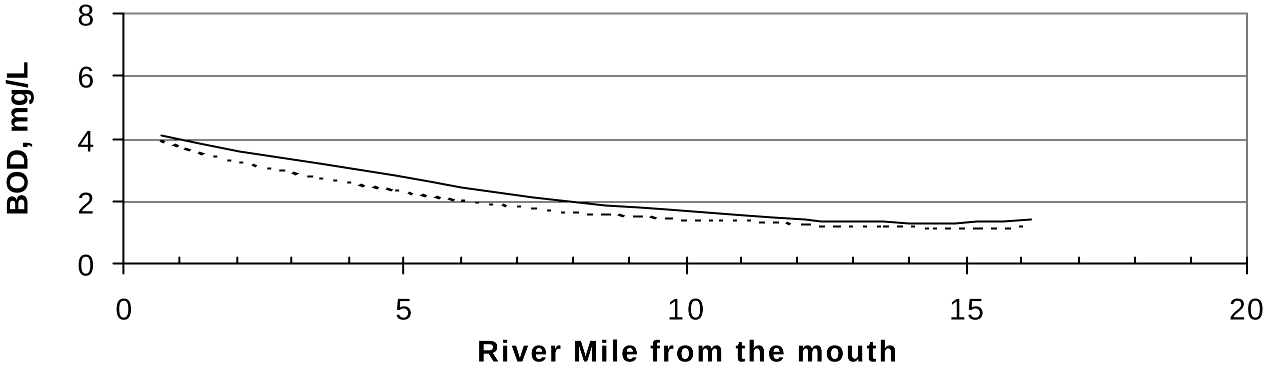

Figure A50: BOD vs. River Mile for the Future Average Flow TMDL Scenario

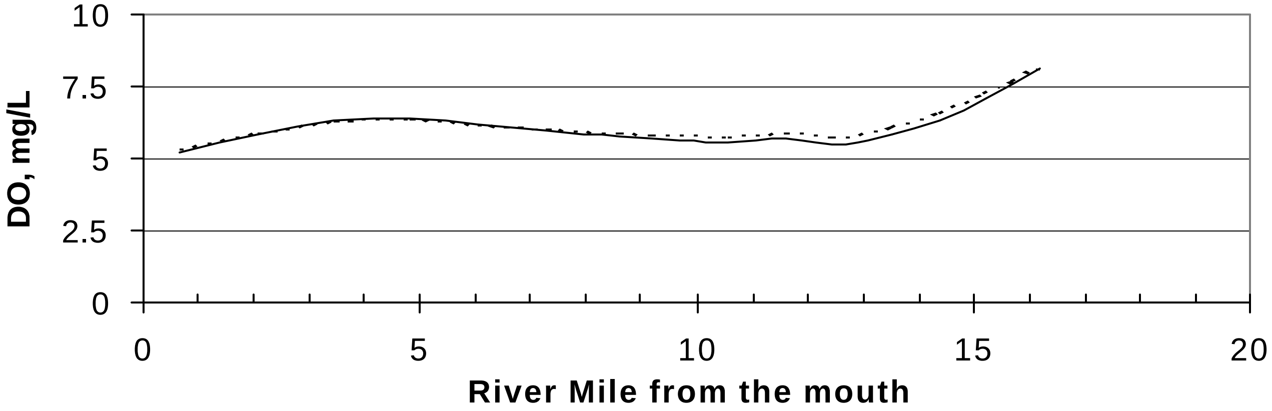

Figure A51: Dissolved Oxygen vs. River Mile for the Future Average Flow TMDL Scenario

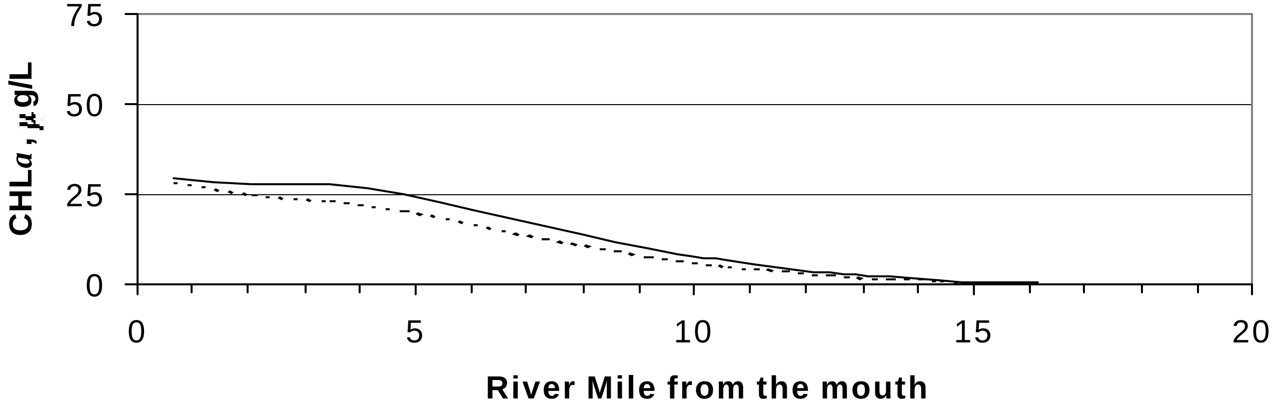

Figure A52: Chlorophyll *a* vs. River Mile for the Future Average Flow TMDL Scenario

___ Base-line Average flow condition **……. Future Average flow TMDL condition**

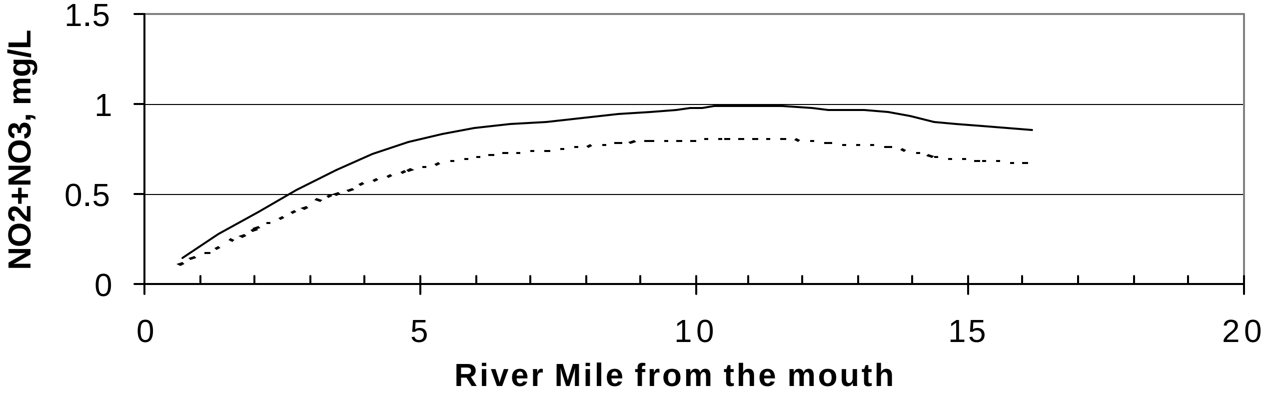

Figure A53: Nitrate (plus Nitrite) vs. River Miles for the Future Average Flow TMDL Scenario

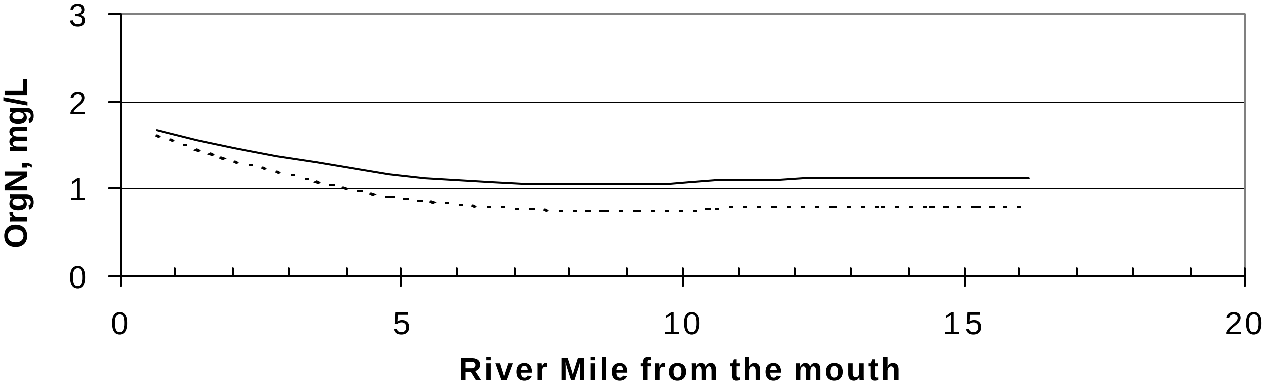

Figure A54: Organic Nitrogen vs. River Mile for the Future Average Flow TMDL Scenario

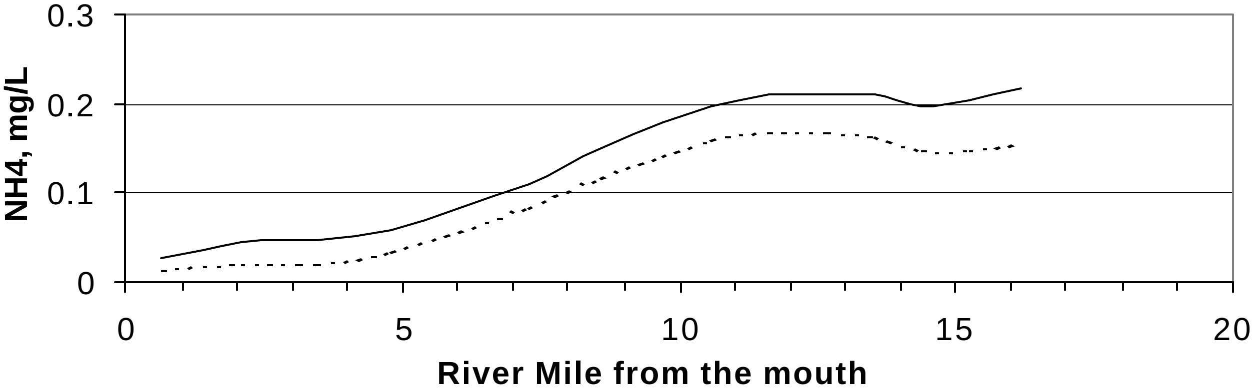

Figure A55: Ammonia vs. River Mile for the Future Average Flow TMDL Scenario

___ Base-line Average flow condition **……. Future Average flow TMDL condition**

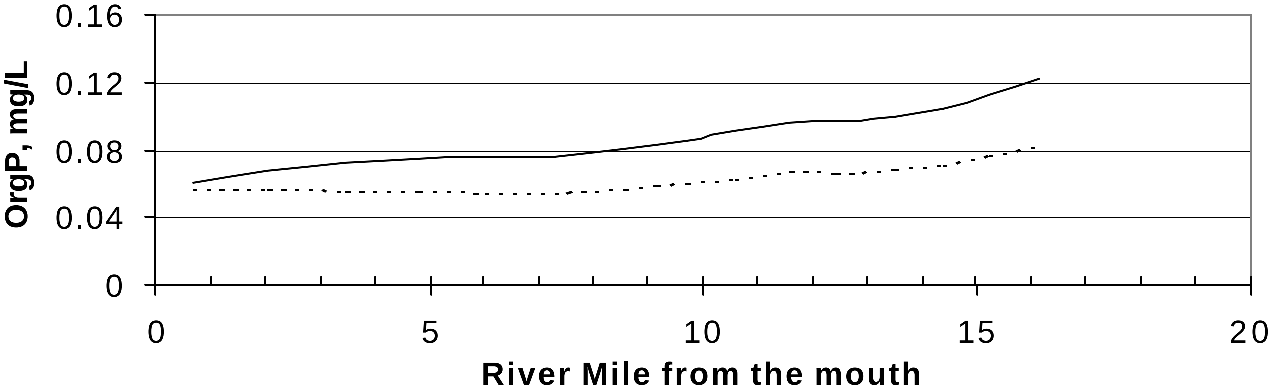

Figure A56: Organic Phosphorus vs. River Mile for the Future Average Flow TMDL Scenario

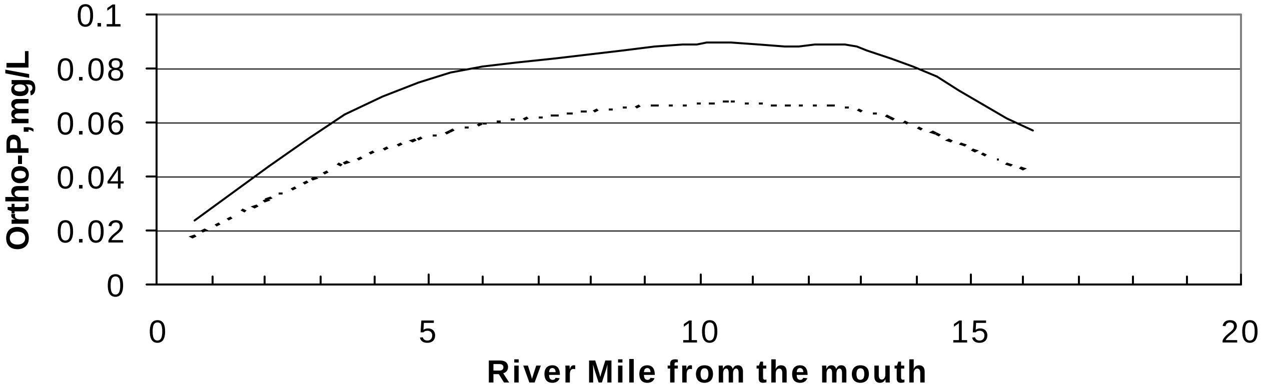

Figure A57: Ortho-Phosphate vs. River Mile for the Future Average Flow TMDL Scenario

___ Base-line Average flow condition **……. Future Average flow TMDL condition**

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