MODELING FRAMEWORK

The computational framework chosen for the modeling of water quality in the Sassafras 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,* 1993). 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

MDE's Field Operations Program staff collected physical and chemical samples on April 1, April 19, May 17, July 26, August 23, and September 27, 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 at Solomon's, 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. Figures A2 – A6 present low flow and high flow water quality profiles along the river.

MODEL INPUT REQUIREMENTS [1]

Model Segmentation and Geometry

The spatial domain of the Sassafras River Eutrophication Model (SREM) extends from the confluence of the Sassafras River and the Chesapeake Bay for about 16 miles (25 km) up the mainstem of the River. Following a review of the bathymetry for the Sassafras River, the model was divided into 27 segments. Figure A7 shows the model segmentation for the development of SREM. Table A2 lists the volumes, characteristic lengths and interfacial areas of the 27 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 simulate salinity. Salinity is a conservative constituent, which means there are no losses due to reactions in the water. The only source in the system is the salinity from the water at the tidal boundary at the mouth. For model execution, salinity values at all boundaries, except the tidal boundary, were set to zero. Flows were obtained from regression equations for both low flow and high flow using data from USGS gage station in Kent County, Maryland (see the section on freshwater flows for more details). Figure A8a represents all salinity data collected in 1999. Figure A8b shows the data used for calibration and the model output for low flow and high flow periods in 1999. Due, in great part, to fresh water intrusions from high flow events from the Susquehanna River, the salinity profiles are unstable for some period, or showed a reverse gradient in salinity from the river mouth to the river head. For this reason, observed data collected in September (low flow) as well as April (high flow) were excluded from the model calibration process. Dispersion coefficients are listed in Table A3.

Freshwater Flows

Freshwater flows were calculated on the basis of delineating the Sassafras River drainage basin into 22 subwatersheds (Figure A9). These subwatersheds closely correspond with the Maryland Department of Natural Resources 12-digit basin codes. Where necessary, the subwatersheds were refined to assure they were consistent with the 27 segments developed for the SREM. The SREM was calibrated for two sets of flow conditions: high flow and low flow. For reasons explained above, the high flow corresponds to the month of May only, while the low flow corresponds to the months of July and August.

The high flows for the subwatersheds were estimated using an average flow from the month of May 1999 from the USGS gages #01493000, #01493112, and #01493500 located near the Sassafras River. A ratio of flow to drainage area was calculated and then multiplied by the area

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. Following are several conversion factors to aid in the comparison of numbers in the main document: mgd x (0.0438) = m^3/s | cfs x (0.0283) = m^3/s | lb / (2.2) = kg | ml (0.625) = km | mg/L x mgd x (8.34) / (2.2) = kg/d

of the subwatersheds to obtain the high flows. During high flow, each subwatershed was assumed to contribute a flow to the Sassafras River (see Figure A7, model segmentation).

The low flows for the subwatersheds were also estimated based on the flow to drainage-area ratio of the three USGS gages as described above using flow data from the months of July and August, 1999. The September data was excluded because it corresponded to an unusual high flow event (Hurricane Floyd). As in high flow, it was assumed that during the summer, each subwatershed was assumed to contribute a flow to the Sassafras River.

The average flows were also estimated based on the flow to drainage-area ratio of the three USGS gages. The average flow was calculated using the flow data from March to September 1999. Table A4 presents the flows for the subwatersheds during high flow, low flow, low flow baseline, and average flows.

Nonpoint Source Loadings

Nonpoint source loadings were estimated for high flow, low flow and average annual flow conditions. For nonpoint sources, the concentrations of the nutrients nitrogen and phosphorus are modeled in their speciated forms. The WASP5.1 model simulates nitrogen as ammonia (NH_3), nitrate and nitrite ($NO_{2\text{-}3}$), 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.

Loads for the high flow and low flow calibrations were estimated as the product of observed concentrations during high flow and low flow 1999, multiplied by their respective estimated flows. These nonpoint source loads for the calibration of the model were calculated using data from eleven water quality stations within the Sassafras River Basin. Water quality data from the 1999 survey was used to estimate boundary concentrations as follows: station XJH2956 was used for segment 1, station XJI2192 was used for segment 14, station XJI2603 was used for segment 15, station XJH1785 was used for segment 17, station XJI1313 was used for segment 19, station XJI1632 was used for segment 20, station XJI1446 was used for segments 21 and 22, station XJI1776 was used for segment 23, station XJI1686 was used for segment 24, station XJI2941 was used for segment 26, station XJI2358 was used for segment 27. The boundary conditions for the segment 11 was based on average concentrations calculated using stations XJI1446 and XJI1776.

Average annual loads were determined using all the data collected by MDE Field office in 1999. An average of March, April, May, July, August and September flow and concentrations for each station was calculated and the boundaries' concentrations were assigned in the same way as described above for high and low flow. Both calibration loads and average annual loads reflect natural and human sources, including atmospheric deposition, loads coming from septic tanks, loads coming from urban development, agriculture, and forestland.

Point Source Loadings

For point source loads, the concentrations of all eight parameters simulated by the model are considered in the same speciated forms as described above in the Nonpoint Source Loadings section.

Two point sources that discharge nutrients into the system were considered for the analysis. The Betterton WWTP discharges directly near the mouth of the Sassafras River. The Galena WWTP discharges into Dyer Creek, which drains to the upper part of the river (water quality model, segment 11).

The point source loadings used in the calibration of the model were calculated from actual WWTP flows and concentrations stored in MDE's point source database. For higher stream flow conditions, point source loads were simulated as an average of May 1999 discharge report data. For low flow stream conditions, point source loads were simulated as an average of July and August 1999 discharge report data. These data coincide with the time period in which data was collected and use for model calibration. Table A6 presents the point source flows and loadings used for the model calibration.

The point source loadings used for the baseline low flow scenario (first scenario) and for the baseline average annual flow scenario (second scenario) were calculated from the maximum allowable limit effluent concentrations described in the plant's surface water discharge NPDES permit (see scenario descriptions below). For model input parameters for which there is no maximum permit limit, concentrations were estimated based on the type of unit operations or treatment processes used by each plant under consideration.

Environmental Conditions

Eight environmental parameters were used for developing the model of the Sassafras River. They are solar radiation and photoperiod (see Table A5), temperature (T), extinction coefficient (K_e), salinity, sediment oxygen demand (SOD), sediment ammonia flux (FNH_4) and sediment phosphate flux (FPO_4) (Table A7).

Data for the solar radiation and photoperiod were taken from a water quality model study performed on the Potomac River on 1982 (HydroQual, 1982). Data for salinity and temperature were taken from in-stream water quality measurements. Initial values of SOD, FNH_4 and FPO_4 were estimated then refined through the calibration process.

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

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

where:

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

It was estimated that nonliving organic nutrient components settle from the water column to the sediment at an estimated settling velocity of 0.0432 *m/day* or (5E10^{-7} *m/sec*), and phytoplankton was estimated to settle through the water column at a rate of 0.0259 *m/day* or (3E10^{-7} *m/sec*). These values are within the range specified in the WASP5.1 manual. In general, it is reasonable to assume that 50% of the nonliving organics are in the particulate form.

Different SOD values were estimated for different SREM reaches based on observed environmental conditions and literature values (Thomann, 1987). The lowest SOD value of 0.1 $g\ O_2/m^2 day$ was assumed to occur in the area upstream of the head of tide of the creek. A maximum SOD value of 3.0 $g\ O_2/m^2 day$ was used in the area downstream (see Table A7).

Kinetic Coefficients

The water column kinetic coefficients are universal constants used in the SREM 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 A8.

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 salinity, which was used to estimate the dispersion coefficients, was calibrated with July and August 1999 salinity data. Figure A8b shows the salinity calibration for low and high flow periods. More information about the dispersion coefficients can be found in the *Model Input Requirements* section above.

The EUTRO5.1 model for low flow was calibrated with July and August 1999 data. Tables A9, A10 & A11 shows the nonpoint source flows and loads associated with the calibration input file (See *Point and Nonpoint Sources Loadings* above for details). Figures A10 – A17 show the results of the calibration of the model for low flow. As can be seen, in Figure A10 the model was able to replicate the BOD trend, although it did not capture the peak value. In Figure A11, the model did a good job of capturing the trend in the dissolved oxygen data. However, the calibration overestimates of chlorophyll *a* concentrations at approximately 5 – 7 km from the mouth of the river (Figure A12). One possible reason might be that, at the junction of Tumer Creek with the Sassafras River, the river has a rather complex configuration, which is difficult to model. It is also possible that the observed data reflect a transition in concentration rather than a steady state concentration.

The model was able to replicate the nitrate trend (Figure A13) and did an excellent job of capturing the trend in the organic nitrogen data (Figure A14). Also, a reasonably good approximation of the model results and the input data for ammonia was not achieved (as show in Figure A15). One may note, however, a big variation of the observed data values that are more typical for nonsteady flow processes. Figures A16 and A17 show how well the model simulated the organic phosphorus and the ortho-phosphate data.

The EUTRO5.1 model for high flow was calibrated with May 1999 data. The results are presented in Figures A18 to A25. The model did well in capturing almost all the state variables. Only one exception is the ortho-phosphate; however, this is not significant given that the range of values is very small.

A model sensitivity analysis was performed on the calibration and on the baseline condition scenarios for low flow and average annual flow to determine the reaction of the model to reductions in both nitrogen and phosphorus. The model was sensitive to reductions in phosphorus. However, it was not sensitive to reductions in nitrogen. During low flow conditions a 100% increase in point source and nonpoint source total nitrogen loads had no effect on chlorophyll *a* or dissolved oxygen concentrations. Table A12 shows ratios of Dissolved Inorganic Nitrogen (NH_4 + NO_2 + NO_3) to Dissolved Inorganic Phosphorus (PO4). The ratio of DIN to DIP in all segments indicates that phosphorus limits the algal growth.

MODEL LIMITATIONS

Two related modeling limitations and their implications, are noteworthy. These two limitations are both related to fresh water intrusions from high-flow events from the Susquehanna River. These are observed in the salinity profile data collected in 1999 (Figure A8a).

The first limitation is the application of the WASP5.1 in a steady-state mode. Generally, tidal systems vary over an annual cycle, but have a low stream-flow period during summer and early fall in which the system approximates a steady state. This period is truncated in the case of the Sassafras River due to the time for recovery from the large spring flow from the Susquehanna and an unseasonably large flow that occurred in September of 1999. Consequently, the present modeling results should be interpreted in this context, with the expectation that an eventual time-variable analysis is warranted.

The second limitation involves the nutrient source assessment, as it pertains to the Susquehanna/Bay as a potential source. It is evident that high-flow events from the Susquehanna River influence the salinity concentrations in the Sassafras River (Figure A8a). In addition, preliminary results of sediment transport modeling in the Upper Chesapeake Bay indicate an interaction of the Susquehanna/Bay with the Sassafras River (Personal Communications, H. Wang, Virginia Institute of Marine Sciences, 2001). However, determining the nutrient-related effects is an active area of research that is beyond the scope of this TMDL analysis. Nevertheless, the potential implications of this phenomenon are acknowledged in the section entitled "Assurance of Implementation."

SYSTEM RESPONSE

The EUTRO5.1 model of the Sassafras River was applied to several different nonpoint source loading conditions under various stream flows to project the impacts of nutrientson algal production (modeled as chlorophyll *a*) and low dissolved oxygen. By simulating various stream flows, the analysis accounts for seasonality.

Model Run Descriptions

Baseline Condition Scenarios:

First Scenario(Low Flow): The first scenario represents the baseline low flow conditions of the stream. The low flow was estimated using a regression analysis as described above in the flows section using the 7Q10 values for the USGS stations specified above in the Freshwater Flows section. The nonpoint source loads for this scenario were the same nonpoint source loads used in the low flow calibration of the model and computed as described above in the Nonpoint Source Loads section. These nonpoint source loads are shown in Table A13. Because the loads are based on observed concentrations, they account for all background and human-induced sources. All the environmental parameters used for the first Scenario remained the same as for the low flow calibration of the model. The point sources used in this scenario were calculated as described above in the section "Point Source Loadings" and are shown in Table A14.

Second Scenario (Average Annual Flow): The second scenario represents the baseline conditions of the stream during average annual flow. The total average annual flow was estimated based on data from the USGS gages as described above and are shown in Table A15. Nonpoint source load estimation methods are described above. Point source loadings were the same used in the first scenario. All the environmental parameters remained the same as in the first scenario - except temperature. Temperature for this scenario was estimated by averaging the summer temperatures from the Chesapeake Bay Program 12-year historical data in the Maryland Eastern Shore area. This summer average temperature of 26 ^{o}C was used for all segments – a conservative assumption.

Future Condition TMDL Scenarios:

Third Scenario (Low Flow): The third scenario is the final result of a number of iterative model scenarios involving nutrient reductions that were explored to determine the maximum allowable loads during low flow conditions. For this scenario, the flow was the same as Scenario 1. The total nonpoint source loads were based on the 1999 MDE field data and reduced to meet the water quality criteria specified before. The point source loads reflect the plant's maximum water and sewer plant design flow and effluent concentrations as in the first scenario and remain the same (there were no reductions in point source loads) for reasons explained below. 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. A description of the methods used to estimate the reductions of nonpoint and point sources, as well as nutrient fluxes and SOD for this scenario, are described in the following paragraphs.

- To estimate feasible phosphorus nonpoint source reductions, the percent of the nonpoint source 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. A margin of safety of 5% was included in the load calculation. Using the above calculated percent controllable, several iterative reductions were made to the nonpoint source loadings starting with a 10% reduction of phosphorus controllable loads up to the final phosphorus reductions used for the future low flow condition scenario. Not all phosphorus loads were reduced in the same proportions geographically. In the Low Flow TMDL scenario, all phosphorus loads except the loads coming into segments 14, 15 and 24 were reduced by 40%. Phosphorus loads coming into segments 14, 15 and 24 had to be reduced 70% from the baseline scenario. These reductions in nonpoint source loads, combined with the original point source loads from the baseline conditions scenario, meet the chlorophyll *a* goal of 50 µg/L, and the dissolved oxygen criterion of no less than 5.0 mg/L.

- The point sources loads were estimated using the plants maximum design flow and maximum permit effluent concentrations. The nonpoint source loads were not reduced from the first scenario baseline conditions. The two point sources located in the Sassafras River watershed, Betterton and Galena WWTPs, both have flows below 0.3 million gallons per day. Because of these low flows, biological nutrient removal (BNR) upgrades have not been implemented. Also, as noted in the main document, they have a negligible effect in the water quality of the river because of the location and concentrations of these point sources of nutrients. More information about point source loads can be found in the technical memorandum entitled "*Significant Phosphorus Point Sources in the Sassafras River Watershed*".

- 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* entering the model boundaries. For the model scenarios in which the nutrient loads to the system were reduced, a method was developed to estimate the reductions in nutrient fluxes and SOD from the botton 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 baseline condition scenario once with estimated settling of organics and chlorophyll *a*, then again with no settling. The difference in the amount of 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 to sediment from the algae, it was assumed that the nitrogen to chlorophyll *a* ratio was 7.5, and the phosphorus to chlorophyll *a* ratio was 0.75. This analysis was then repeated for the reduced nutrient loading conditions. The percentage difference between the amount of nutrients that settled in the baseline 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 sediment nutrient fluxes, to a minimum of 0.3 $gO_2/m^2\ day$

- Also, for the same model scenarios in which the nutrient loads to the system were reduced, a method was developed to estimate the reductions in chlorophyll *a* concentrations entering the river model boundaries. First, potential chlorophyll *a* concentrations based on the baseline scenario nitrogen and phosphorus boundary concentrations were calculated. Then, potential chlorophyll *a* concentrations were calculated again based on the reduced nitrogen and phosphorus boundary concentrations. These potential chlorophyll *a* concentrations were estimated based on the following relationships:
  - $\textit{Potential Chlorophyll a based on Nitrogen} = N \times \left(\frac{Chla}{N}\right)$ where:

    N = Total dissolved nitrogen concentration at each boundary

    $\frac{Chla}{N}$ = Chlorophyll *a* to nitrogen ratio used in the model = 0.133
  - $\textit{Potential Chlorophyll a based on Phosphorus} = P \times \left(\frac{Chla}{P}\right)$ where:

    P = Total dissolved phosphorus concentration at each boundary

    $\frac{Chla}{P}$ = Chlorophyll *a* to phosphorus ratio used in the model = 1.33

The smaller of the two values calculated above were then used for the calculation of the percentage reduction. This percentage reduction is calculated by estimating the difference between the baseline scenario potential chlorophyll *a* concentrations and the chlorophyll *a* concentrations estimated with the reduced concentrations. These percent reductions are then applied to the baseline chlorophyll *a* concentrations and these reduced concentrations were used together with the reduced nitrogen and phosphorus loads in the TMDL scenarios.

<u>*Fourth Scenario (Average Annual Flow)*</u>: The fourth scenario represents improved conditions associated with the maximum allowable loads to the stream during average annual flow. The flow was the same as in the second scenario. The phosphorus loads were reduced from the

second scenario (average annual flow baseline scenario) to meet chlorophyll *a* and dissolved oxygen standards in the same way as in the third scenario. A 3% margin of safety was included in the load calculation. All environmental parameters and kinetic coefficients used for the calibration of the model (except nutrient fluxes and SOD) remained the same as in the second scenario. The nonpoint source loads for model scenario 4 can be seen in Table A17.

Scenario Results

Baseline Condition Scenarios:

First Scenario (Low Flow): The first scenario simulates the summer low flow conditions when water quality is impaired by high chlorophyll *a* levels, and low dissolved oxygen concentrations. Nonpoint source loads and water quality parameters are the same as those used in the low flow calibration and are based on 1999 observed data. Point source loads were based on the maximum allowable effluent limits as described above in the Point Source Loadings section. The results for this first scenario can be seen in Figures A26-A33. As shown in the figures, the peak chlorophyll *a* level is around the value of 100 μg/l, which is well above the management goal of 50 μg/l. The dissolved oxygen level is above the water quality criterion of 5.0 mg/l throughout the water body system.

Second Scenario (Average Annual Flow): The second scenario simulates average stream flow conditions, with average annual nonpoint source loads estimated from all MDE data collected in 1999. Results for this scenario, representing baseline conditions for average stream flow and loads, are summarized in Figures A34-A41. Under these conditions, the chlorophyll *a* concentrations are also above the desired goal of 50 μg/L with a maximum close to 150 μg/L, but the dissolved oxygen concentrations remain above the 5.0 mg/L criterion throughout the length of the river.

The SREM calculates the daily average, minimum, and maximum dissolved oxygen concentrations in the stream. Accounting only for the daily average DO concentrations is not necessarily protective of water quality when one considers the effects of diurnal dissolved oxygen variation due to photosynthesis and algal respiration. 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 creating a potential for a fish kill. Thus, for the rest of the model results, the minimum dissolved oxygen concentration is reported, to make sure that the chlorophyll *a* concentrations due to the TMDL loadings will not lower the DO concentrations below the standard of 5.0 mg/l.

<u>Future Condition TMDL Scenarios</u>:

<u>*Third Scenario (Low Flow):*</u> The third scenario simulates the future condition of maximum allowable loads for critical low stream flow conditions during the summer season. The results of this scenario (solid line), which corresponds to the maximum allowable loads for summer low flow conditions, are shown in Figures A42-A49 in comparison to the corresponding baseline scenario (dotted line). It can be seen that under the nutrient load reduction conditions, the water quality targets for dissolved oxygen and chlorophyll *a* are met at all locations in the Sassafras River.

<u>*Fourth Scenario (Average Annual Flow)*</u>*:* The fourth scenario simulates the future condition of maximum allowable loads under average stream flow and average annual loading conditions. The results for this scenario (solid line), which corresponds to the maximum allowable loads for average annual flow, are summarized and compared to the corresponding base-line flow (dotted line) in Figures A50-A57. Again the water quality criteria for dissolved oxygen (greater than 5 mg/l) and chlorophyll *a* (less than 50 μg/l) are met for the entire length of the Sassafras River.

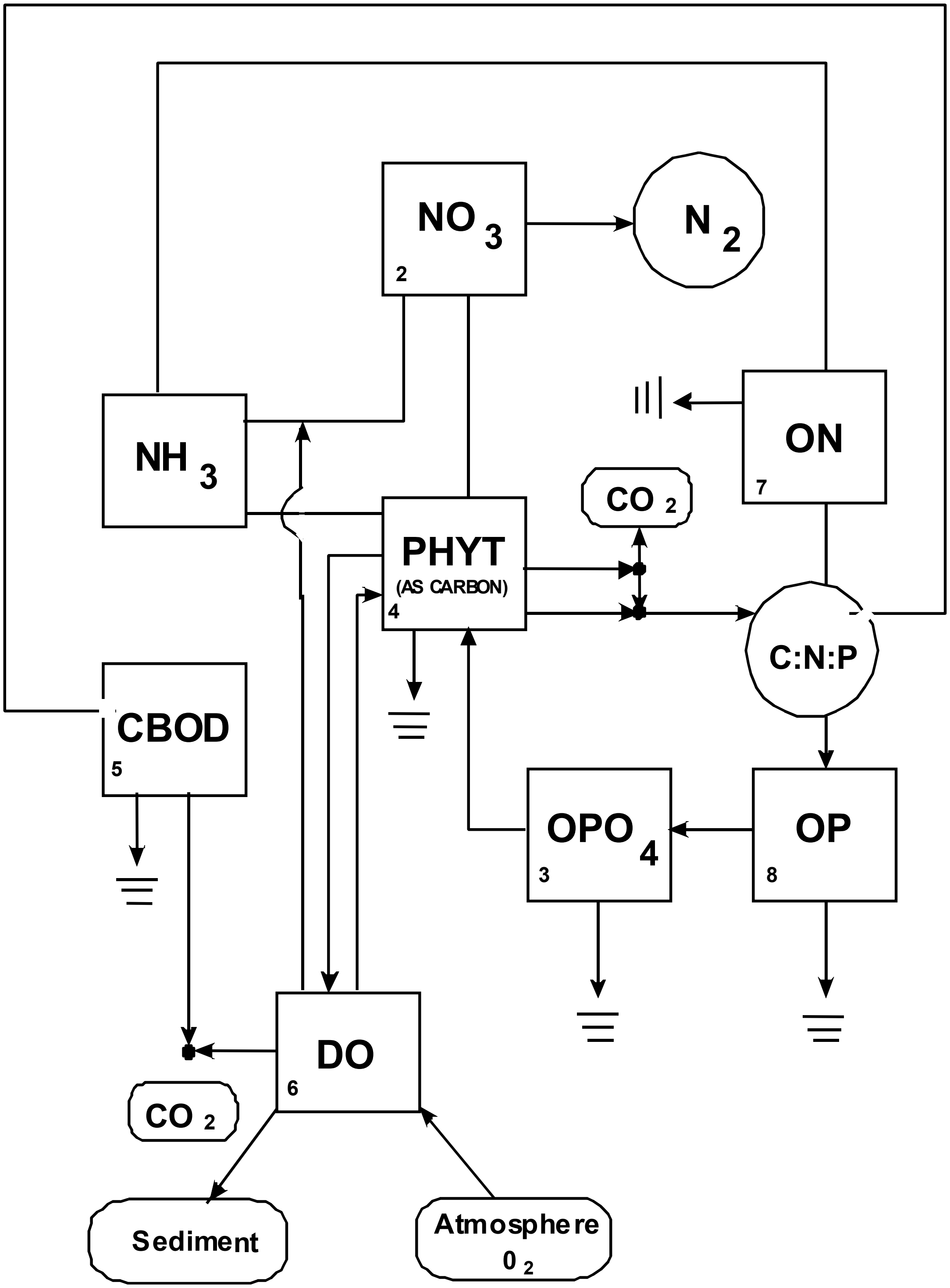
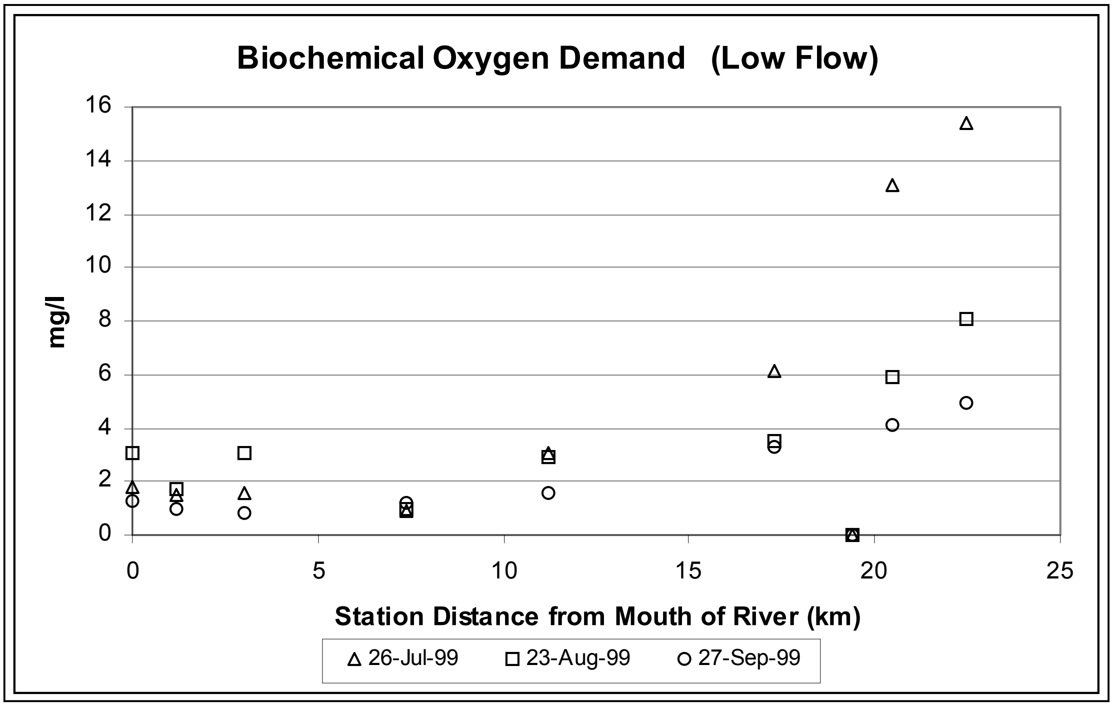


Figure A1: State Variables and Kinetic Interactions in EUTRO5

Table A1: Field and Laboratory Protocols

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



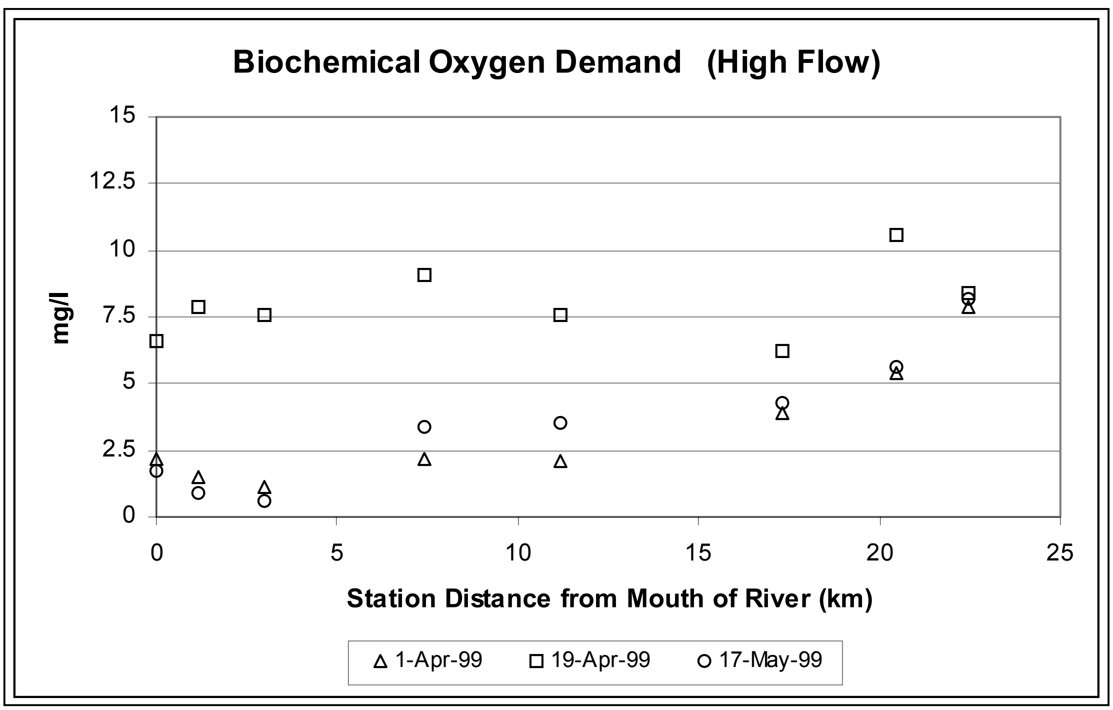


Figure A2: Longitudinal Profile of Biological Oxygen Demand (BOD) Data

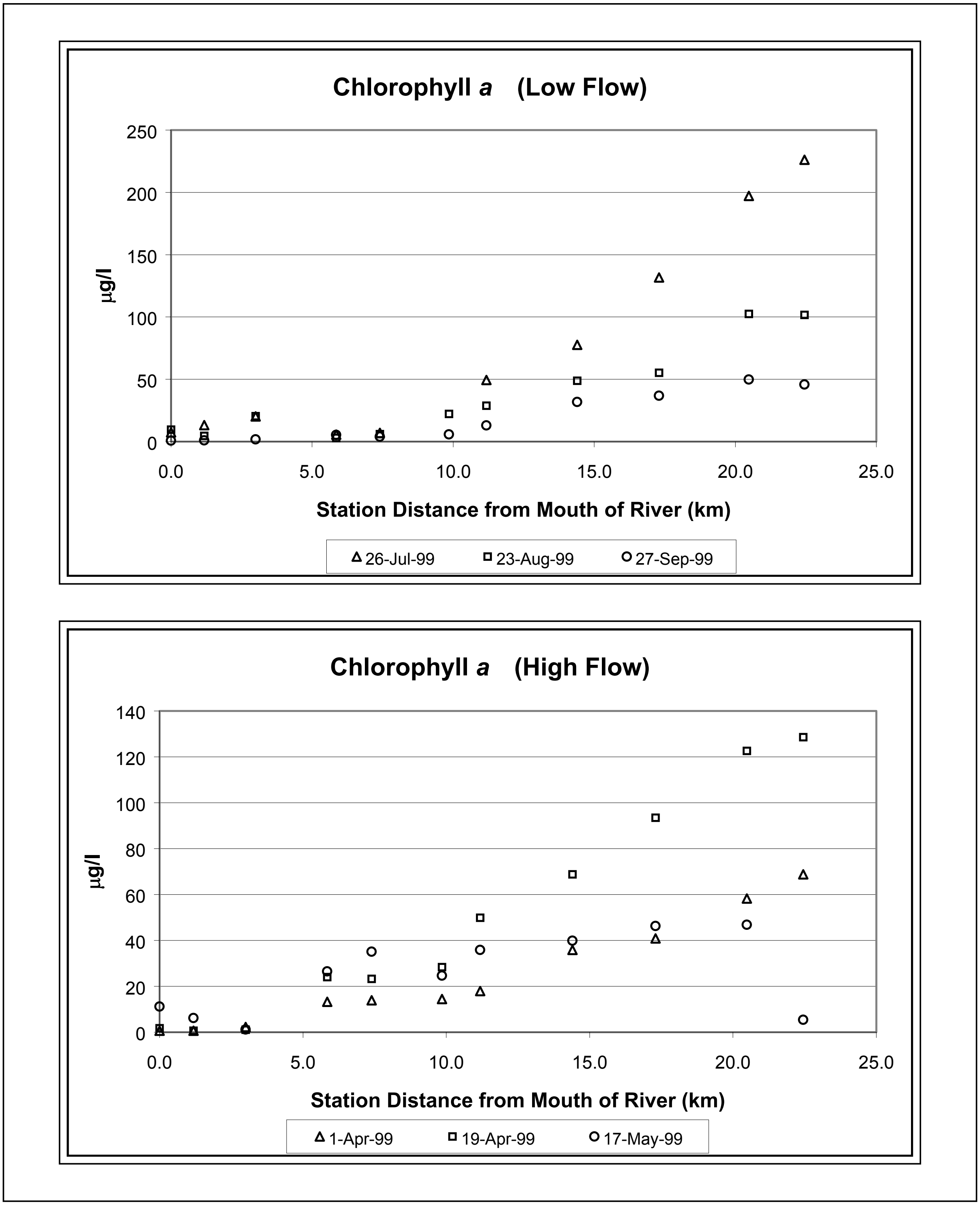
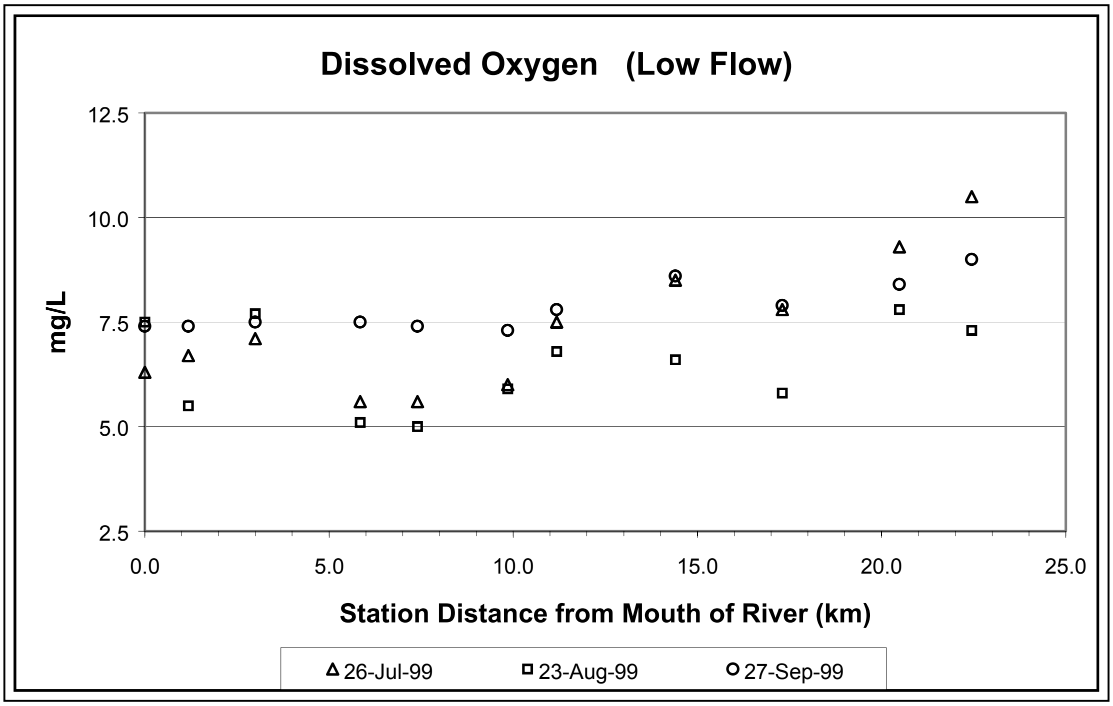


Figure A3: Longitudinal Profile of Chlorophyll *a* data



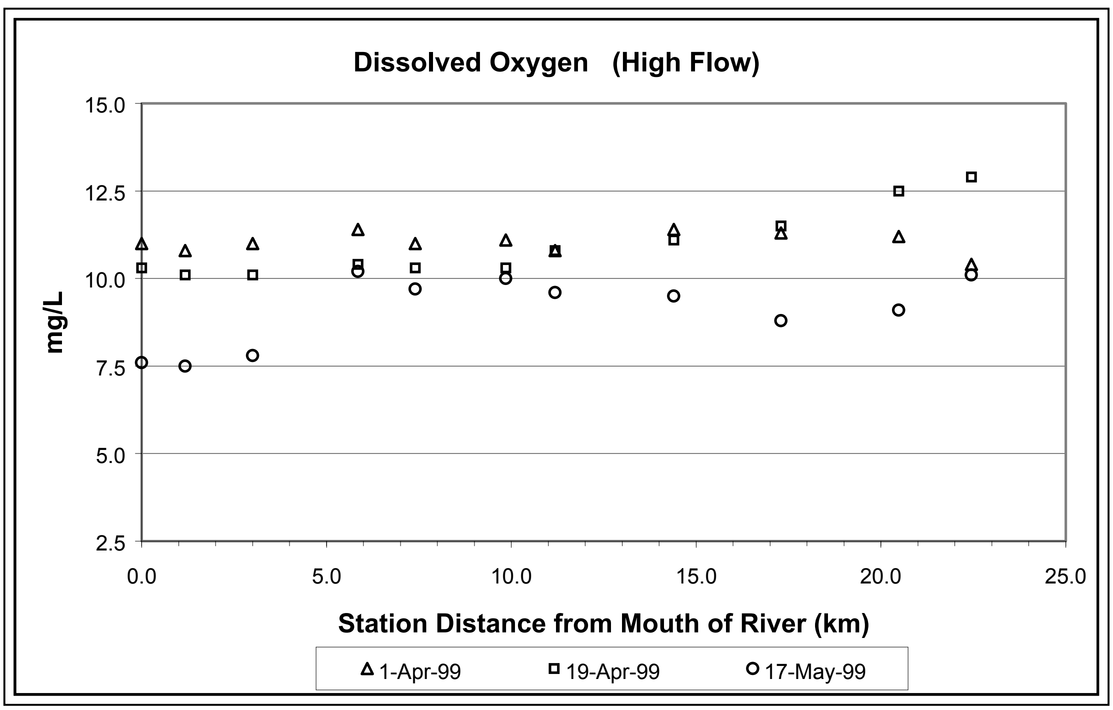


Figure A4: Longitudinal Profile of Dissolved Oxygen Data

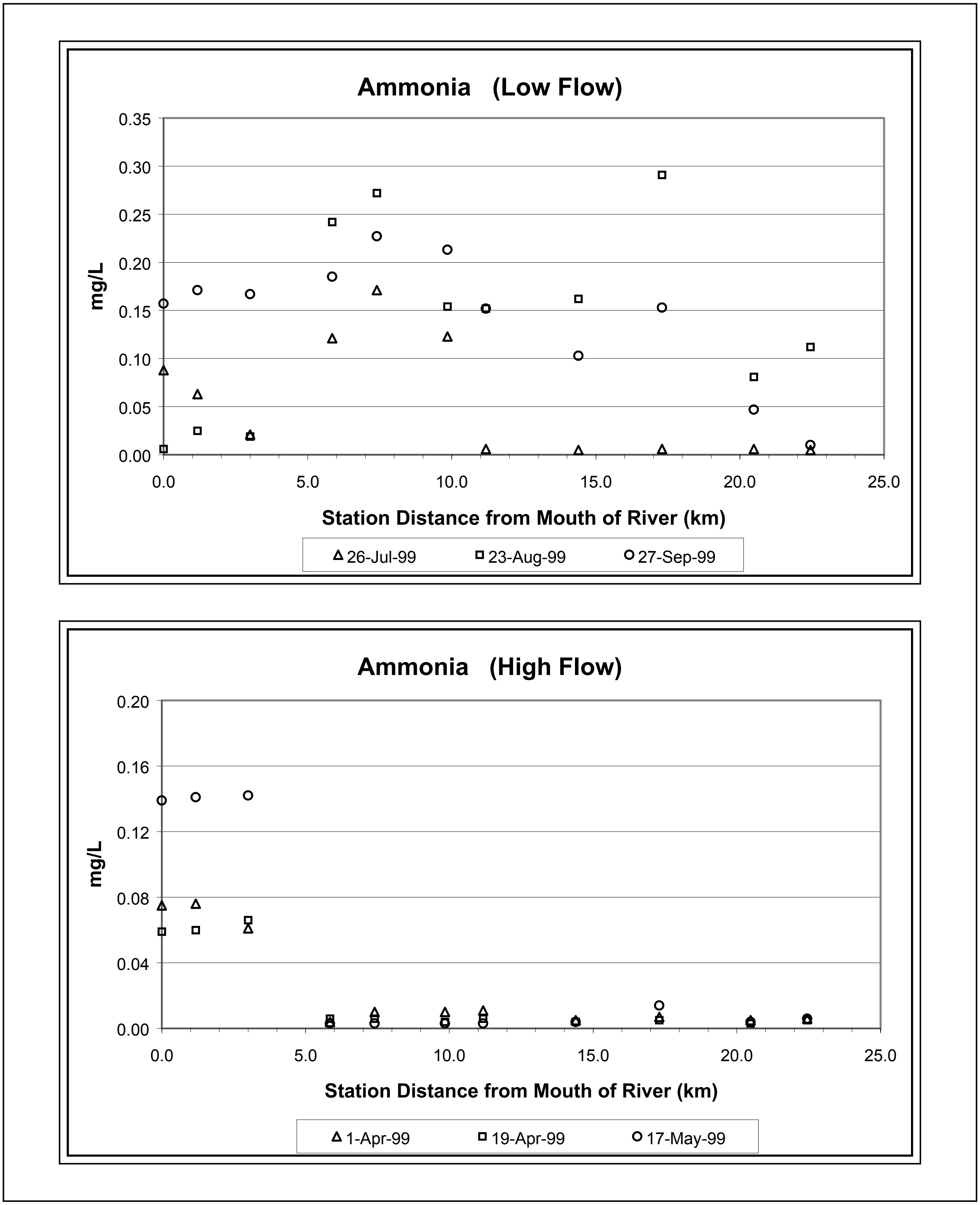


Figure A5: Longitudinal Profile of Ammonia Data

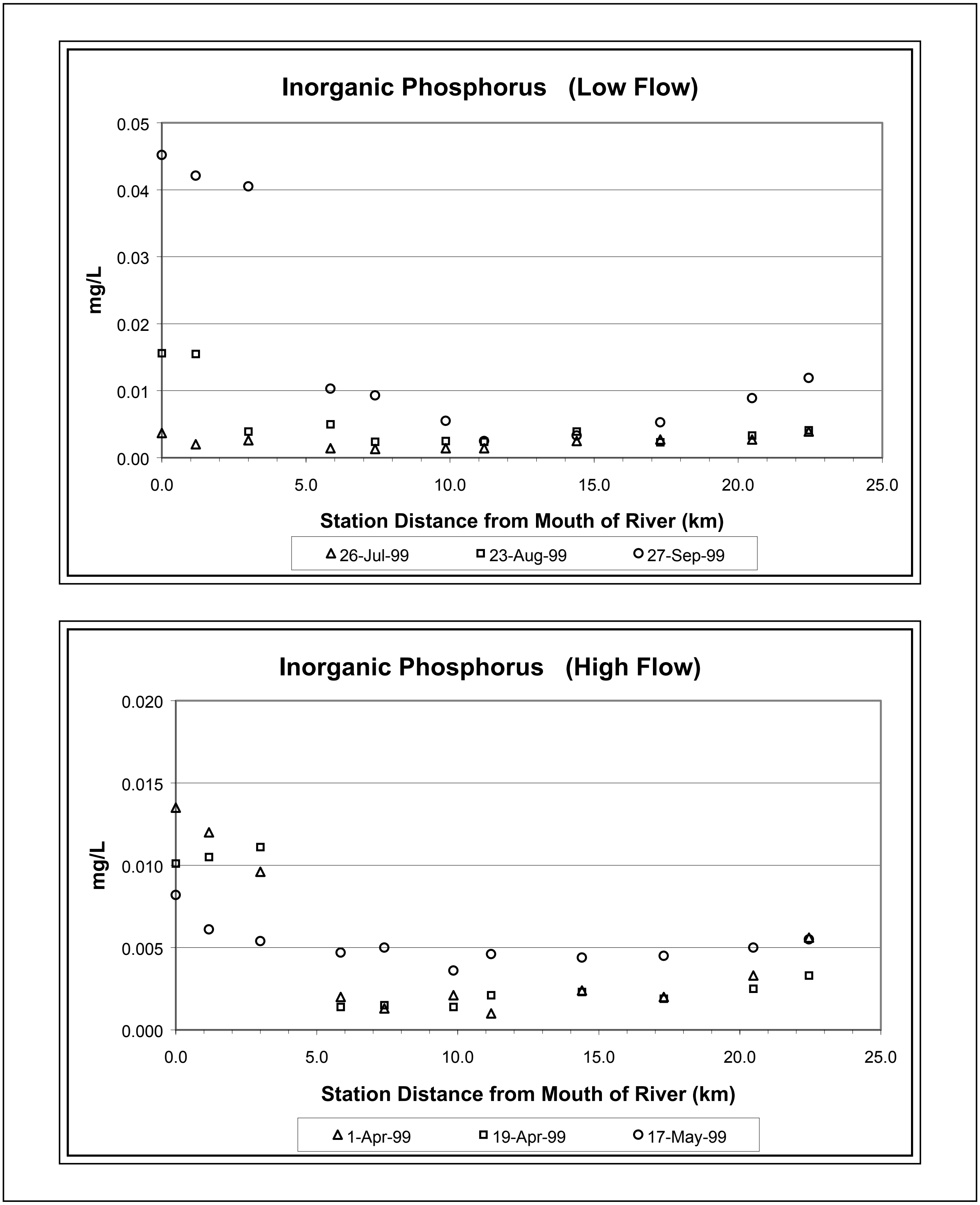


Figure A6: Longitudinal Profile of Inorganic Phosphorus Data

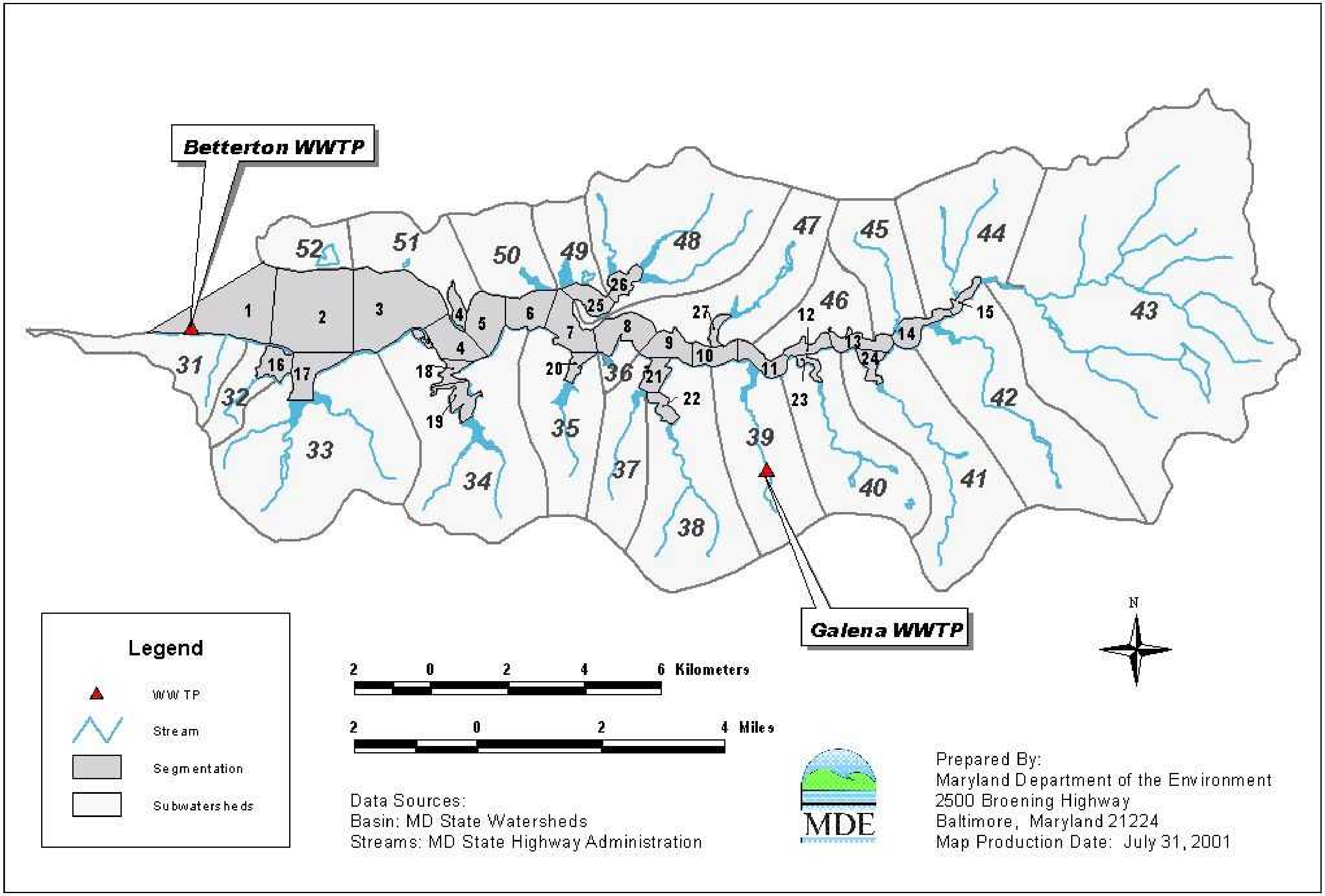


Figure A7: Model Segmentation, including Subwatersheds

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

Segment Number	Volume m^3
1	11893564
2	13776124
3	13563244
4	4987214
5	3884196
6	3367441
7	3301137
8	3190751
9	2025414
10	1732570
11	1982829
12	1241071
13	1091936
14	768180
15	115388
16	322810
17	1764609
18	629620
19	497340
20	379946
21	580260
22	105336
23	261000
24	440943
25	1133028
26	428233
27	188756

Segment Pair	Interfacial Area m^2	Characteristic Length m
0-1	12674	1095
1-2	6417	1780
2-3	6516	2150
3-4	3749	1825
4-5	3246	1250
5-6	2763	1085
6-7	3124	1315
7-8	1802	1615
8-9	1873	1445
9-10	1632	1195
10-11	1436	1385
11-12	837	1425
12-13	951	1450
13-14	312	1710
14-15	138	1515
15-0	97	860
2-17	3292	1750
17-0	533	1050
17-16	453	680
4-18	1460	840
18-19	854	800
19-0	217	950
7-20	908	1200
20-0	149	735
9-21	1073	900
21-0	82	700
21-22	158	1850
22-0	53	700
11-0	316	750
12-23	327	800
23-0	142	960
13-24	1334	620
24-0	117	810
14-0	648	1000
7-25	878	540
25-26	329	1200
26-0	636	1100
10-27	287	600
27-0	52	1100

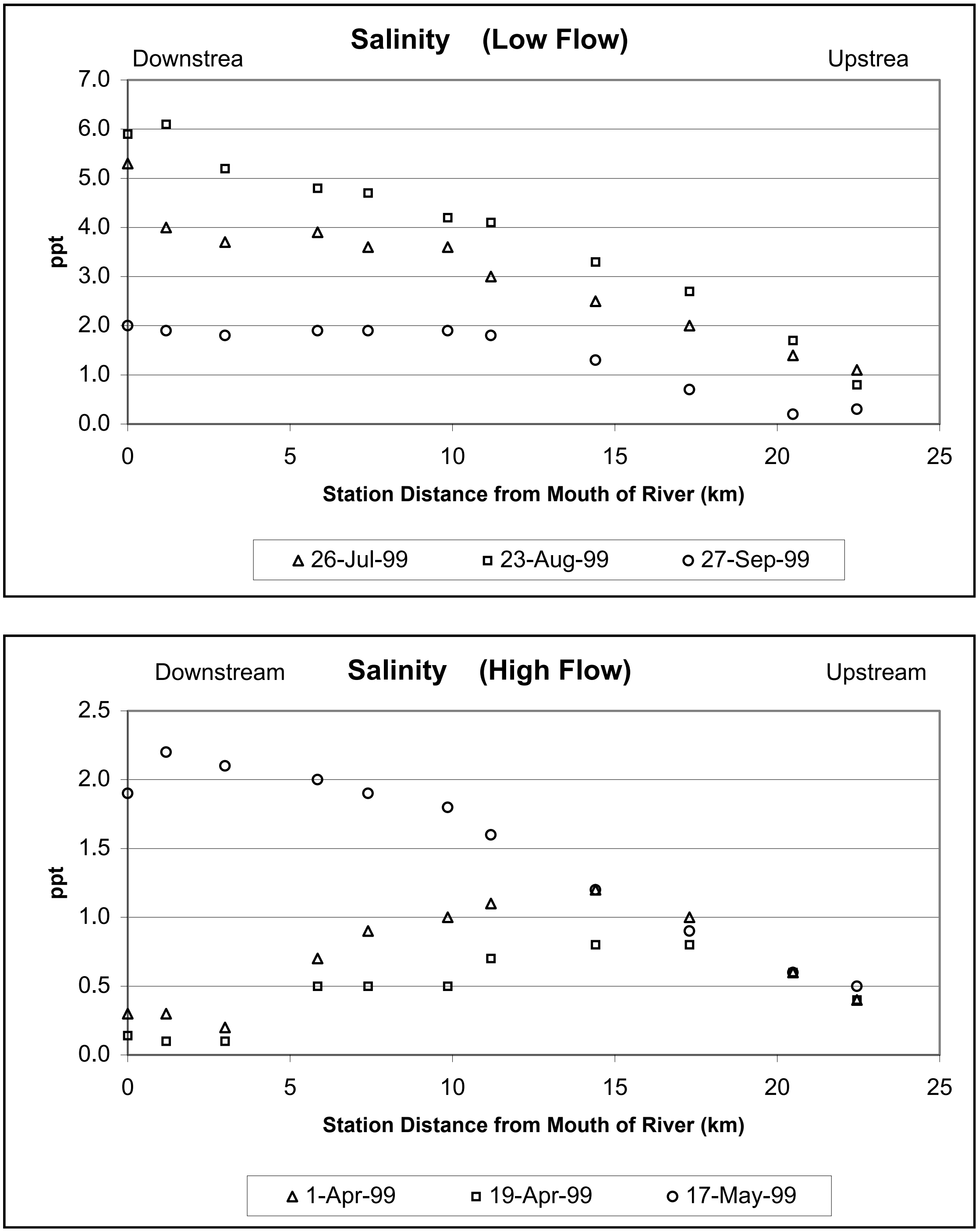


Figure A8a: Longitudinal Profile of Salinity

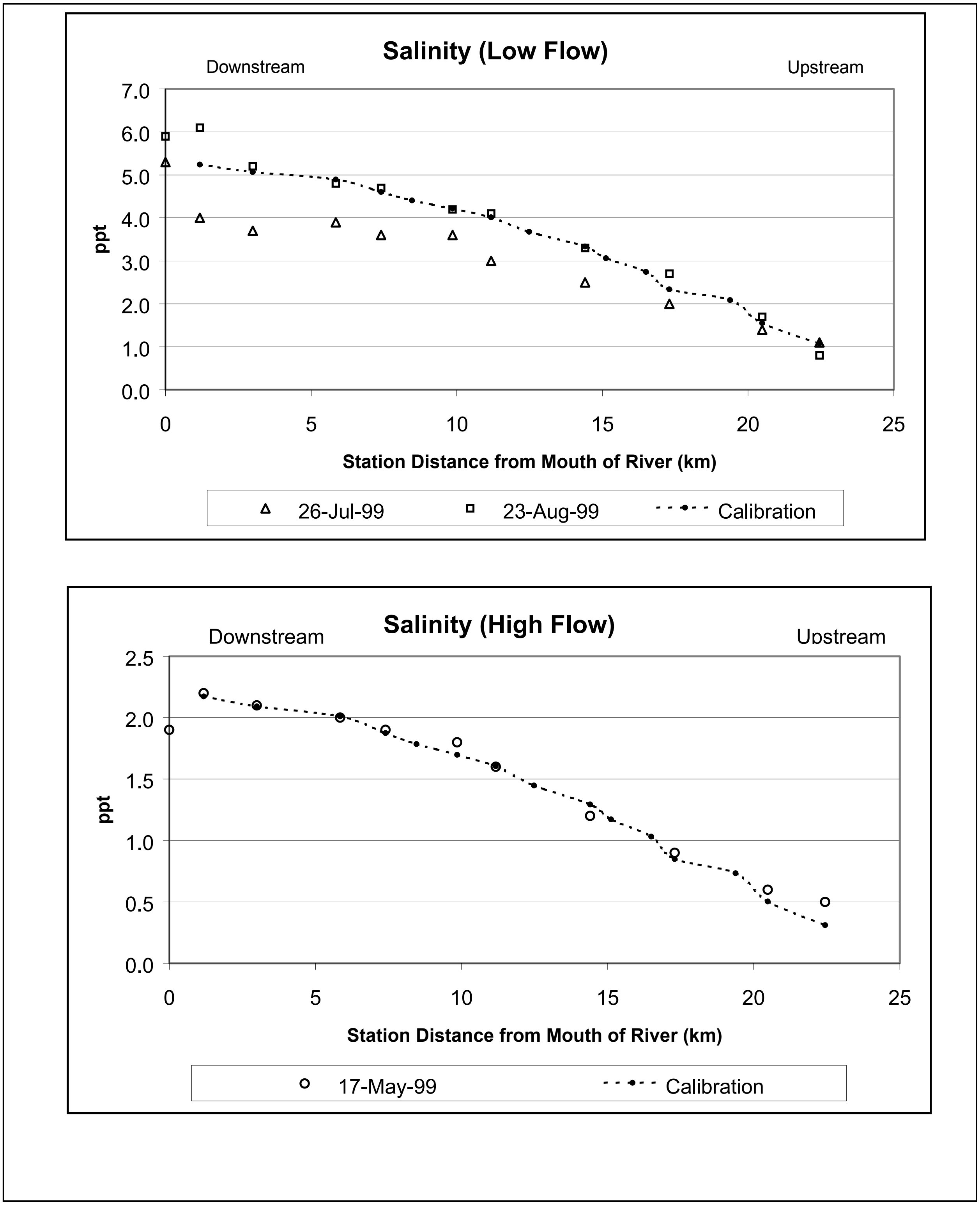


Figure A8b: Results of Calibration of Exchange Coefficiens

Table A3: Dispersion Coefficients used in the SREM

Main River	
Segment Pair	Dispersion Coefficient (m^2/sec)
0 - 1	21.0
1 - 2	21.0
2 - 3	21.0
3 - 4	18.0
4 - 5	18.0
5 - 6	18.0
6 - 7	18.0
7 - 8	15.0
8 - 9	12.0
9 - 10	12.0
10 - 11	12.0
11 - 12	9.0
12 - 13	9.0
13 - 14	9.0
14 - 15	9.0
15 - 0	0.006

Branches	
Segment Pair	Dispersion Coefficient (m^2/sec)
02 - 17	18.0
17 - 0	0.6
17 - 16	6.0
4 - 18	12.0
18 - 19	3.0
19 - 0	1.2
7 - 20	3.0
20 - 0	1.2
9 - 21	12.0
21 - 22	9.0
22 - 0	0.6
21 - 0	0.6
11 - 0	1.2
12 - 23	9.0
22 - 0	1.2
13 - 24	0.6
24 - 0	0.6
14 - 0	0.1
7 - 25	15.0
25 - 26	15.0
26 - 0	0.6
10 - 27	1.8
27 - 0	0.6

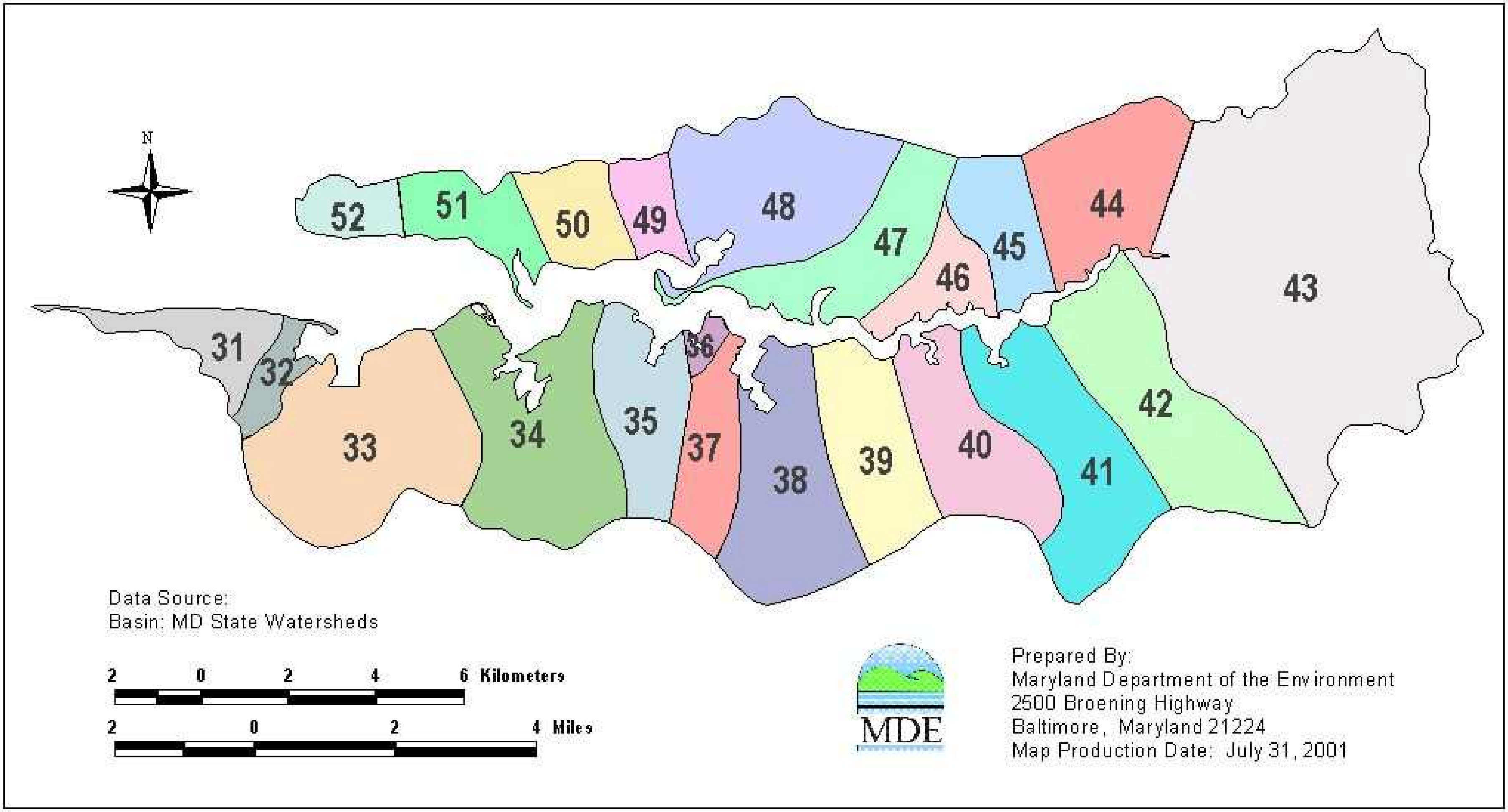


Figure A9: The Twenty Two Subwatersheds of the Sassafras River Drainage Basin

Table A4: Subwatersheds Flow for Low, Baseline Low, High, and Average Conditions

Subwatershed Number	Low Flow (m^3/s)	Baseline Condition Low Flow (m^3/s)	High Flow (m^3/s)	Average Flow (m^3/s)
31	0.0262	0.0081	0.0310	0.0347
32	0.0132	0.0041	0.0156	0.0174
33	0.1030	0.0319	0.1219	0.1361
34	0.0893	0.0276	0.1057	0.1181
35	0.0441	0.0137	0.0522	0.0583
36	0.0045	0.0014	0.0053	0.0060
37	0.0320	0.0099	0.0379	0.0424
38	0.0737	0.0228	0.0872	0.0974
39	0.0532	0.0165	0.0629	0.0702
40	0.0562	0.0174	0.0665	0.0743
41	0.0781	0.0242	0.0925	0.1032
42	0.0853	0.0264	0.1009	0.1127
43	0.3025	0.0936	0.3580	0.3998
44	0.0616	0.0191	0.0729	0.0814
45	0.0323	0.0100	0.0382	0.0427
46	0.0237	0.0073	0.0281	0.0313
47	0.0533	0.0165	0.0631	0.0705
48	0.0822	0.0254	0.0972	0.1086
49	0.0161	0.0050	0.0190	0.0212
50	0.0260	0.0080	0.0308	0.0344
51	0.0298	0.0092	0.0352	0.0394
52	0.0170	0.0053	0.0201	0.0225

Table A5: Solar Radiation and Photoperiod used in the Calibration of the Model

Parameter	**Unit**	**High Flow** (May)	**Low Flow** (July, August)
Solar Radiation	*Langleys*	450.0	450.0
Photoperiod	*Fraction of a day*	0.58	0.58

Table A6: Point Source Loadings for the Calibration of the Model

Parameter*		**Betterton**	**Galena**
Flow	High flow	38.34	119.90
	Low flow	38.34	62.39
NH4	High flow	0.5179	0.2889
	Low flow	0.5179	0.0270
NO23	High flow	0.0587	2.5391
	Low flow	0.0587	1.5818
PO4	High flow	0.0966	0.4220
	Low flow	0.0966	0.2196
CHL a	High flow	--	--
	Low flow	**--**	--
CBOD	High flow	0.2032	2.7537
	Low flow	0.2032	0.9602
DO	High flow	0.2645	0.8871
	Low flow	0.2645	0.3474
ON	High flow	0.1135	0.3201
	Low flow	0.1135	0.0296
OP	High flow	0.0184	0.1187
	Low flow	0.0184	0.0618

*** All loadings in kg/day. Flow in m^3/day**

Table A7: Environmental Parameters for the Calibration of the Model

Segment Number	Ke (m^{-1})		T (^0C)		Salinity (gm/l)		SOD ($g\ O_2/m^2day$)		FNH_4 ($mg\ NH_4\text{-}N/m^2day$)		FPO_4 ($mg\ PO_4\text{-}P/m^2day$)	
	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	2.2	2.2	18.0	19.8	2.17	5.24	0.4	1.0	10.0	40.0	0.5	1.0
2	2.8	2.8	18.3	19.8	2.09	5.07	0.5	2.0	10.0	40.0	0.5	1.0
3	2.8	2.8	18.7	20.1	2.01	4.89	0.6	3.0	10.0	40.0	0.5	1.0
4	3.9	3.9	18.4	20.2	1.88	4.60	0.6	3.0	10.0	40.0	0.5	1.0
5	3.9	3.9	18.6	20.2	1.79	4.41	0.5	2.5	10.0	40.0	0.5	1.0
6	3.9	3.9	19.0	20.3	1.70	4.22	0.4	2.0	10.0	40.0	0.5	1.0
7	4.9	4.9	18.5	20.4	1.61	4.02	0.2	1.0	10.0	40.0	0.5	1.0
8	5.2	5.2	18.5	20.4	1.45	3.68	0.2	0.5	10.0	40.0	0.5	1.0
9	6.5	6.5	18.6	20.4	1.29	3.33	0.2	0.5	10.0	40.0	0.5	1.0
10	6.5	6.5	19.0	20.5	1.17	3.06	0.2	0.5	10.0	40.0	0.4	0.8
11	6.5	6.5	19.4	20.5	1.03	2.74	0.2	0.3	10.0	40.0	0.3	0.6
12	6.5	6.5	19.4	20.6	0.85	2.34	0.1	0.3	10.0	40.0	0.2	0.4
13	6.5	6.5	19.4	20.6	0.73	2.09	0.1	0.2	10.0	40.0	0.2	0.4
14	6.5	6.5	19.4	20.9	0.50	1.55	0.1	0.1	10.0	40.0	0.2	0.4
15	6.5	6.5	19.0	21.1	0.31	1.07	0.1	0.1	10.0	40.0	0.2	0.3
16	7.8	7.8	18.0	20.2	2.06	5.01	0.2	0.3	10.0	40.0	0.5	1.0
17	7.0	7.0	18.0	20.2	2.06	5.01	0.2	0.5	10.0	40.0	0.5	1.0
18	4.2	4.2	18.7	20.6	1.84	4.53	0.2	0.3	10.0	40.0	0.5	1.0
19	3.3	3.3	18.3	20.8	1.64	4.07	0.2	0.1	10.0	40.0	0.5	1.0
20	4.5	4.5	18.3	20.5	1.42	3.56	0.2	0.3	10.0	40.0	0.5	1.0
21	4.9	4.9	18.2	20.9	1.10	3.28	0.2	0.5	10.0	40.0	0.5	1.0
22	6.5	6.5	18.2	20.9	0.92	2.84	0.2	0.5	10.0	40.0	0.5	1.0
23	9.8	9.8	19.1	20.6	0.79	2.20	0.2	0.5	10.0	40.0	0.5	1.0
24	9.8	9.8	18.9	20.8	0.64	1.85	0.3	0.3	10.0	40.0	0.5	1.0
25	9.8	9.8	18.7	20.5	1.58	3.95	0.2	0.2	10.0	40.0	0.5	1.0
26	9.8	9.8	18.5	20.8	1.42	3.58	0.3	0.3	10.0	40.0	0.5	1.0
27	4.9	4.9	18.9	20.6	1.05	2.79	0.3	0.3	10.0	40.0	0.5	1.0

Table A8: EUTRO5 Kinetic Coefficients

Constant	Code	Value
Nitrification rate	K12C	0.08 *day* -1 at 20° C
temperature coefficient	K12T	1.08
Denitrification rate	K20C	0.08 *day* -1 at 20° C
temperature coefficient	K20T	1.08
Saturated growth rate of phytoplankton	K1C	2.0 *day* -1 at 20° C
temperature coefficient	K1T	1.08
Endogenous respiration rate	K1RC	0.05 *day* -1 at 20° C
temperature coefficient	K1RT	1.045
Nonpredatory phytoplankton death rate	K1D	0.05 *day* -1
Phytophankton Stoichometry		
Oxygen-to-carbon ratio	OCRB	2.67 $mg\ O_2 / mg\ C$
Carbon-to-chlorophyll ratio	CCHL	30
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	0.025 *mg* N / L
Phosphorus	KMPG1	0.0025 *mg* P / L
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	0.9
phosphorus	FOP	1.0
Light Formulation Switch	LGHTS	1 = Smith
Saturation light intensity for phytoplankton	IS1	300. *Ly/day*
BOD deoxygenation rate	KDC	0.2 *day* -1 at 20° C
temperature coefficient	KDT	1.05
Half saturation const. for carb. deoxygenation	KBOD	0.5
Reaeration rate constant	K2	0.2 *day* -1 at 20° C
Mineralization rate of dissolved organic nitrogen	K71C	0.035 *day* -1
temperature coefficient	K71T	1.08
Mineralization rate of dissolved organic phosphorus	K58C	0.15 *day* -1
temperature coefficient	K58T	1.08
Phytoplankton settling velocity		0.026 *m/day*
Organics settling velocity		0.043 *m/day*

Table A9: Contributing Watersheds to Each Model Segment, and Flows for the Segments

Segment Number	Contributing Subwatersheds	Low Flow (m^3/s)	Baseline Low Flow (m3/s)	High Flow (m^3/s)	Average Flow (m^3/s)
11	39	0.0532	0.0165	0.0630	0.0703
14	42 + 45	0.1176	0.0364	0.1392	0.1554
15	43 + 44	0.3641	0.1126	0.4308	0.4812
17	33	0.1030	0.0318	0.1218	0.1361
19	34	0.0893	0.0276	0.1057	0.1180
20	35	0.0441	0.0136	0.0522	0.0583
21	37	0.0320	0.0099	0.0379	0.0423
22	38	0.0737	0.0228	0.0872	0.0974
23	40	0.0562	0.0174	0.0665	0.0743
24	41	0.0781	0.0241	0.0924	0.1032
26	48	0.0822	0.0254	0.0973	0.1086
27	47	0.0533	0.0165	0.0631	0.0704

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

Segment Number	**NH4** *mg/l*	**NO_{23}** *mg/l*	**PO_4** *mg/l*	**CHL *a*** *µg/l*	**CBOD** *mg/l*	**DO** *mg/l*	**ON** *mg/l*	**OP** *mg/l*
11	0.1200	0.024	0.0027	82.00	7.3	7.0	1.300	0.1020
14	0.0435	0.049	0.0030	149.80	15.9	8.6	2.232	0.1968
15	0.0585	0.090	0.0040	163.91	19.6	8.9	2.361	0.2503
17	0.0680	0.196	0.0041	9.45	2.2	6.9	0.512	0.0272
19	0.0110	0.002	0.0025	47.60	7.2	9.0	0.951	0.0778
20	0.0380	0.031	0.0023	41.62	5.2	7.4	0.897	0.0739
21	0.0085	0.003	0.0034	65.50	7.5	7.5	1.270	0.1175
22	0.0085	0.003	0.0034	65.50	7.5	7.5	1.278	0.1175
23	0.1660	0.022	0.0027	39.25	11.4	7.2	1.902	0.1728
24	0.0190	0.017	0.0038	153.51	18.4	7.6	2.389	0.2358
26	0.0110	0.003	0.0022	39.50	6.8	7.6	0.963	0.0812
27	0.0675	0.019	0.0028	72.52	82	7.3	1.337	0.1084

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

Segment Number	**NH4** *mg/l*	**NO_{23}** *mg/l*	**PO_4** *mg/l*	**CHL *a*** *μg/l*	**CBOD** *mg/l*	**DO** *mg/l*	**ON** *mg/l*	**OP** *mg/l*
11	0.0070	0.062	0.0045	44.00	7.0	9.0	0.850	0.0750
14	0.0040	0.001	0.0050	46.85	9.4	9.1	1.188	0.0976
15	0.0060	0.004	0.0055	5.38	13.7	10.1	2.100	0.3168
17	0.0090	0.437	0.0044	19.69	4.5	9.6	0.487	0.0327
19	0.0030	0.003	0.0055	43.86	7.8	10.6	0.874	0.0645
20	0.0030	0.085	0.0039	39.87	6.0	10.4	0.925	0.0676
21	0.0030	0.002	0.0045	39.62	6.7	10.1	0.940	0.0759
22	0.0030	0.002	0.0045	39.62	6.7	10.1	0.940	0.0759
23	0.0140	0.033	0.0047	38.88	7.2	8.9	1.135	0.1071
24	0.0030	0.003	0.0051	45.60	8.0	10.0	1.089	0.1033
26	0.0030	0.001	0.0043	37.38	8.0	10.3	0.895	0.0709
27	0.0030	0.043	0.0045	42.86	6.7	9.8	1.075	0.0749

Low Flow Calibration

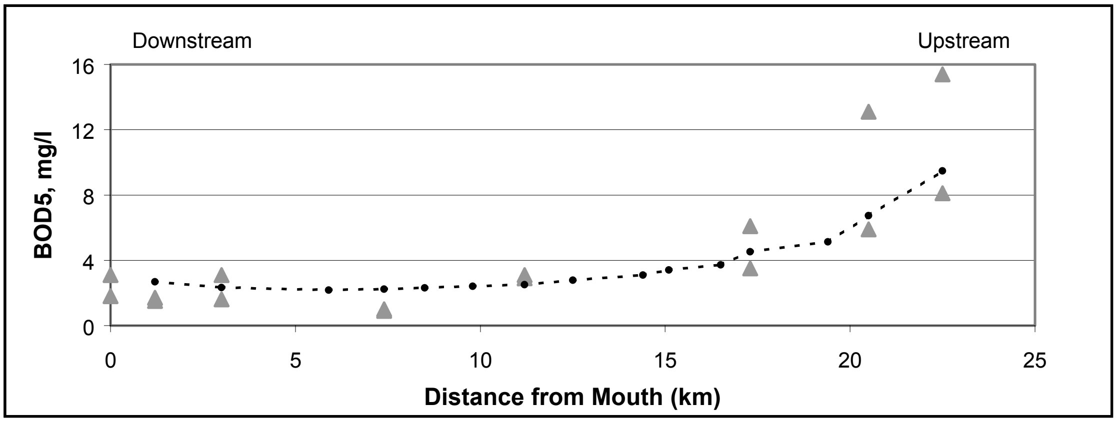


Figure A10: BOD vs. River Mile for the Calibration of the Model (Low flow)

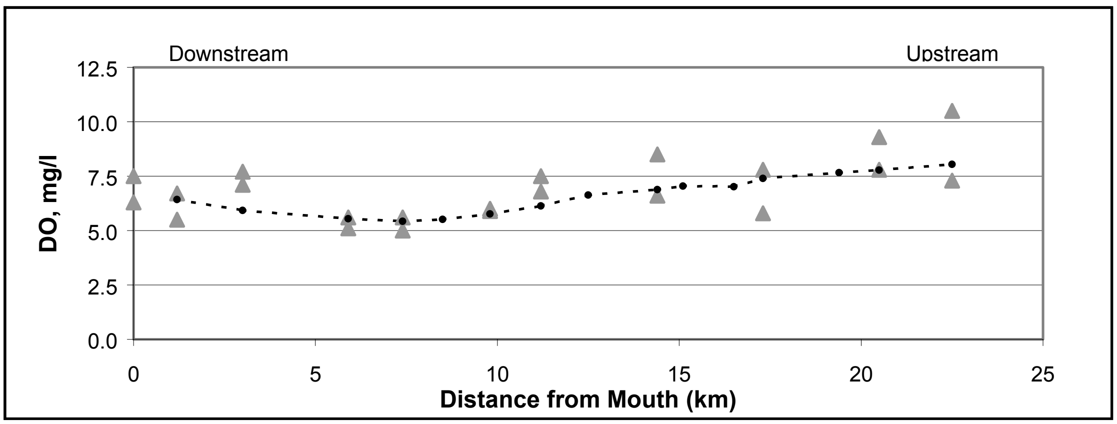


Figure A11: Dissolved Oxygen vs. River Mile for the Calibration of the Model (Low flow)

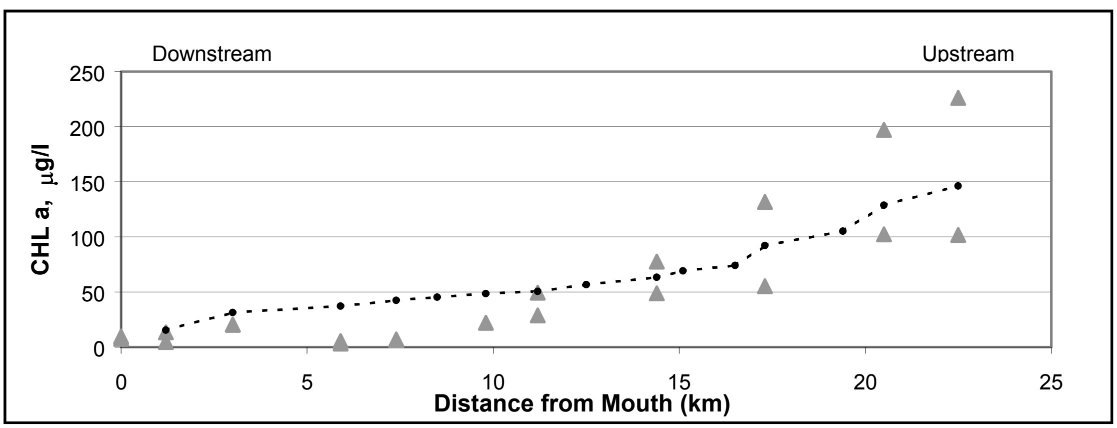


Figure A12: Chlorophyll *a* vs. River Mile for the Calibration of the Model (Low flow)

▲ Monitoring Data **_._._._._._ Calibration**

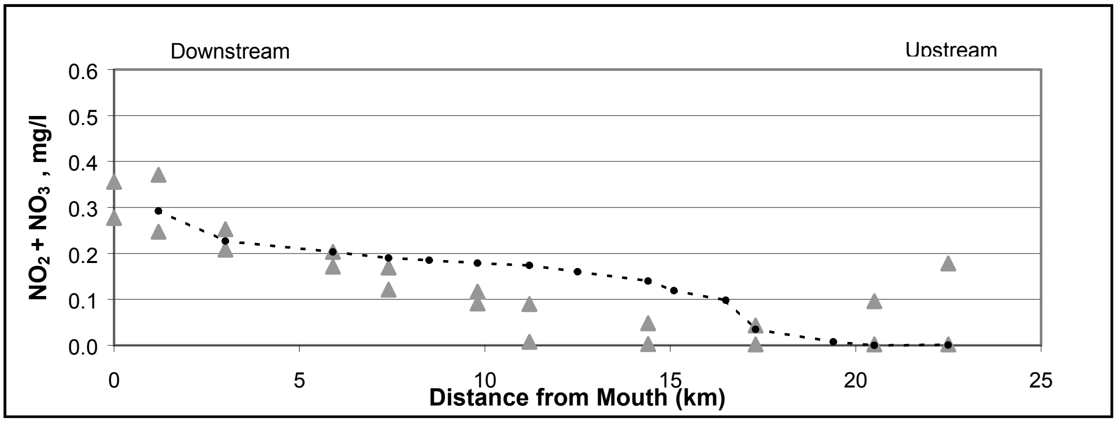
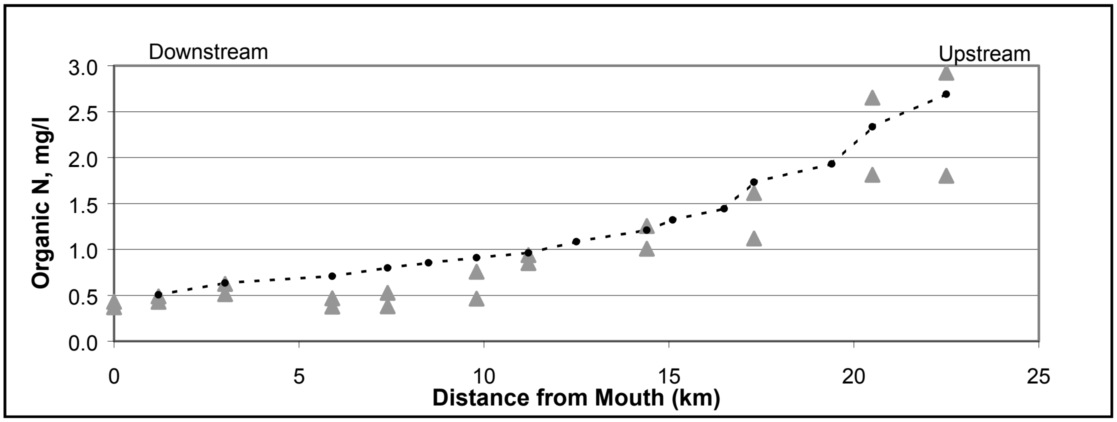


Figure A13: Nitrate (plus Nitrite) vs. River Mile for the Calibration of the Model



(Low flow)

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

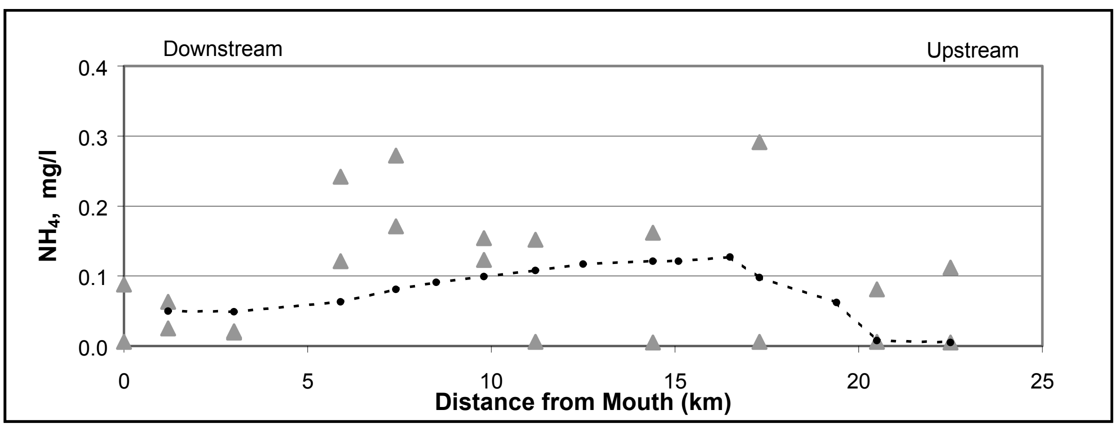


Figure A15: Ammonia vs. River Mile for the Calibration of the Model (Low flow)

▲ Monitoring Data ---------**Calibration**

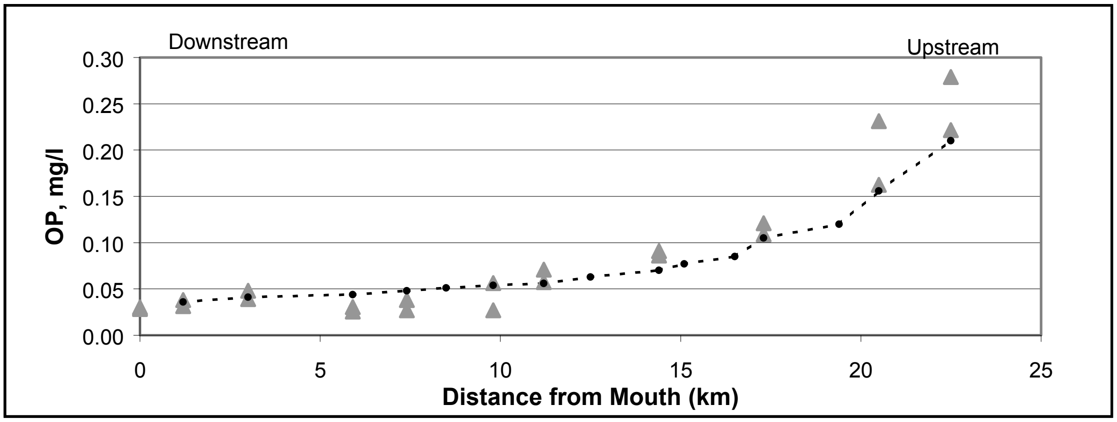


Figure A16: Organic Phosphorus vs. River Mile for the Calibration of the Model (Low flow)

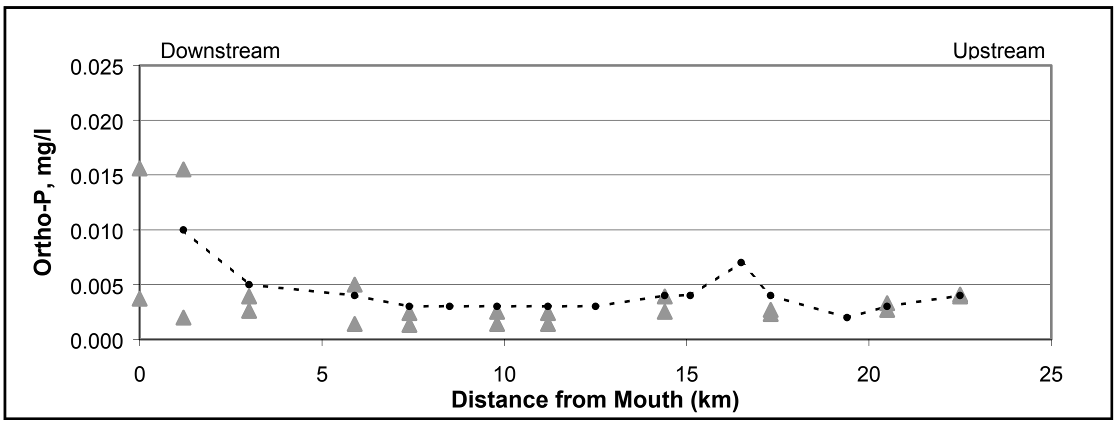


Figure A17: Ortho-Phosphate vs. River Mile for the Calibration of the Model (Low flow)

▲ Monitoring Data _._._._._._._._. **Calibration**

High Flow Calibration

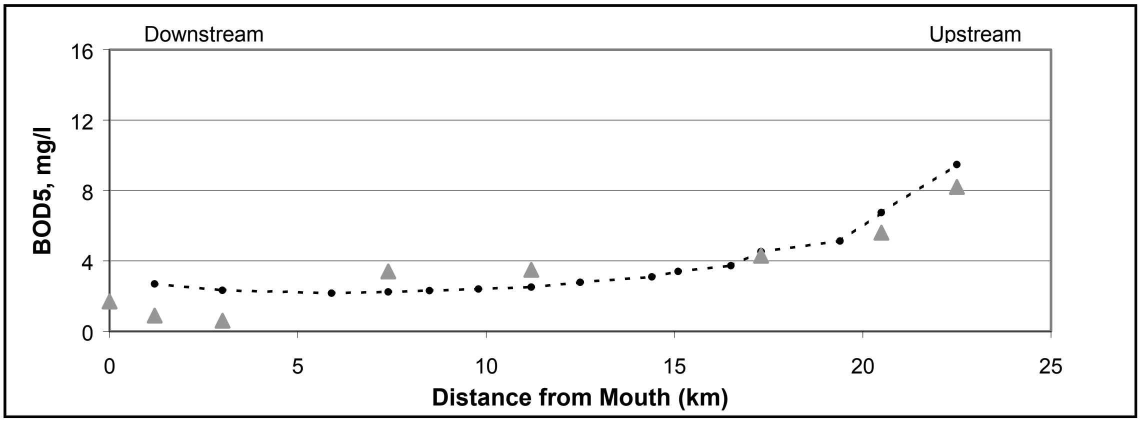


Figure A18: BOD vs. River Mile for the Calibration of the Model (High flow)

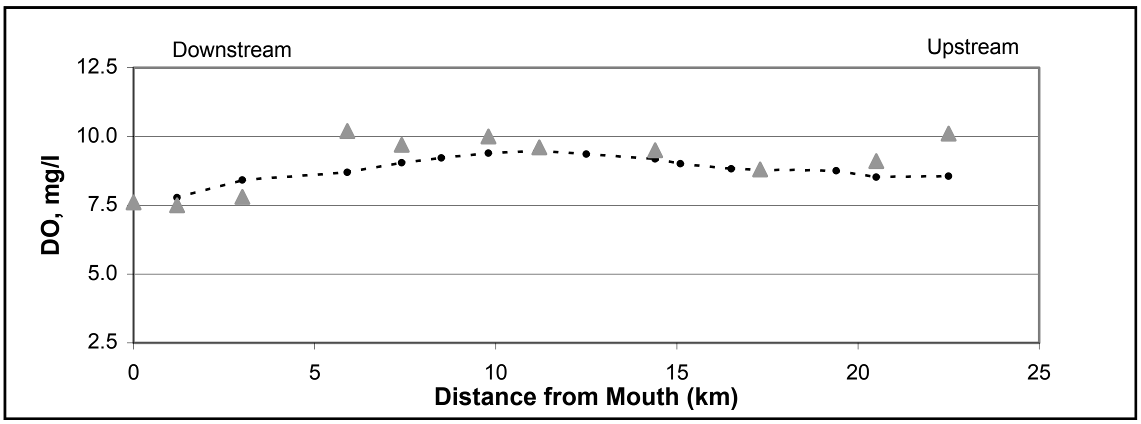


Figure A19: Dissolved Oxygen vs. River Mile for the Calibration of the Model (High Flow)

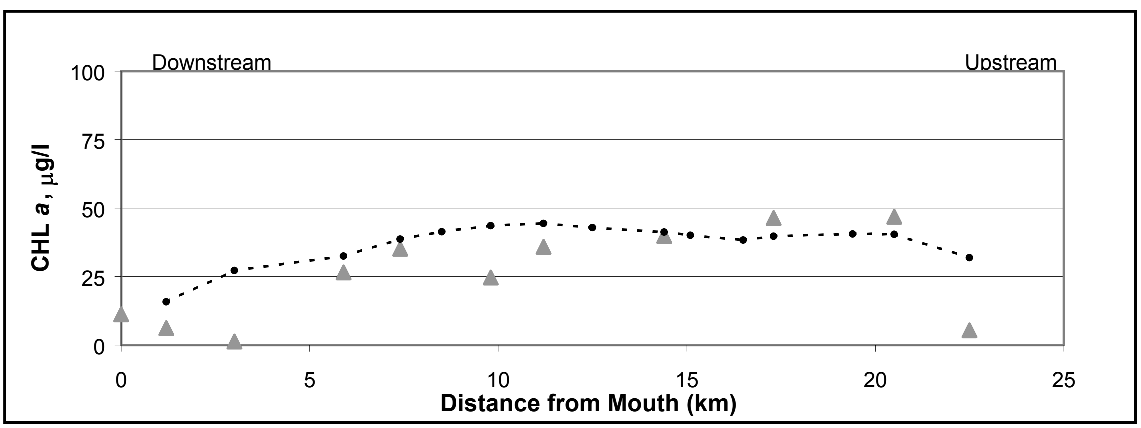


Figure A20: Chlorophyll *a* vs. River Mile for the Calibration of the Model (High flow)

▲ **Monitoring Data** ------------ **Calibration**

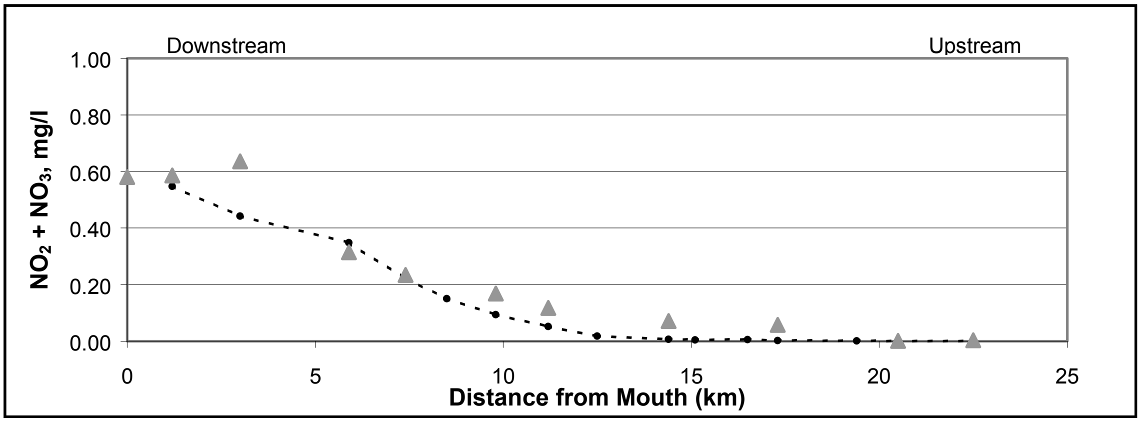


Figure A21: Nitrate (plus Nitrite) vs. River Mile for the Calibration of the Model (High flow)

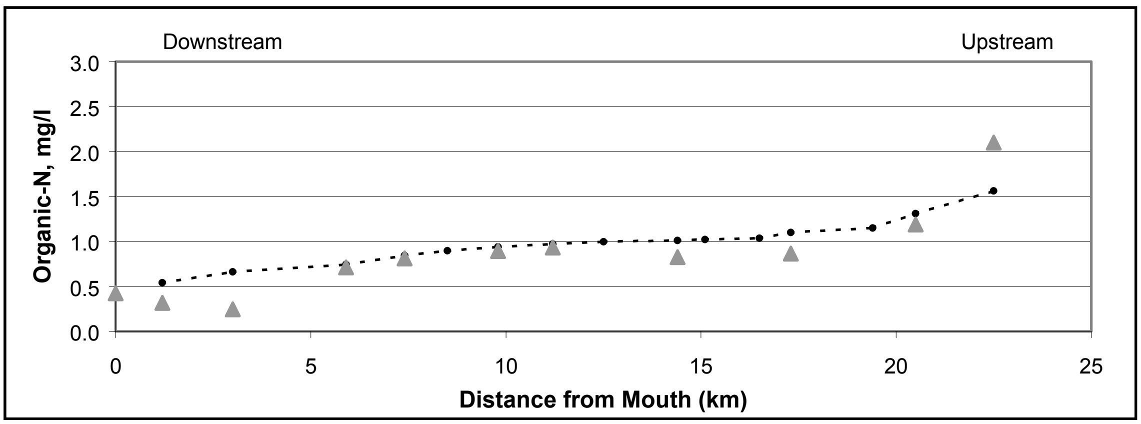


Figure A22: Organic Nitrogen vs. River Mile for the Calibration of the Model (High flow)

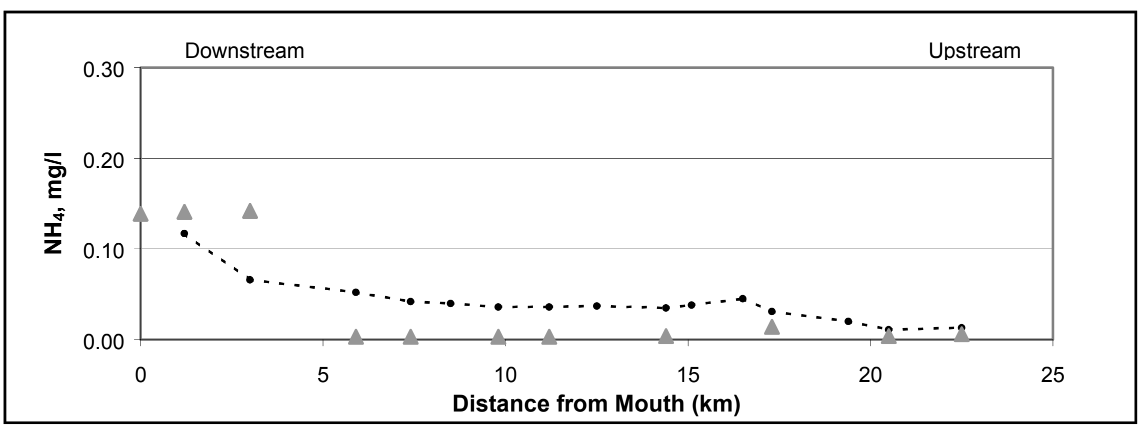


Figure A23: Ammonia vs. River Mile for the Calibration of the Model (High flow)

▲ **Monitoring Data** _._._._._._._._ **Calibration**

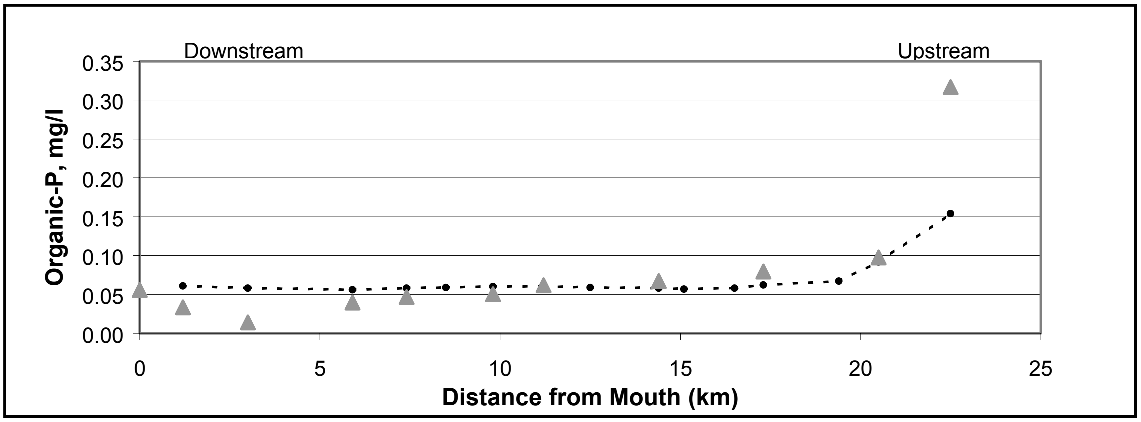


Figure A24: Organic Phosphorus vs. River Mile for the Calibration of the Model (High flow)

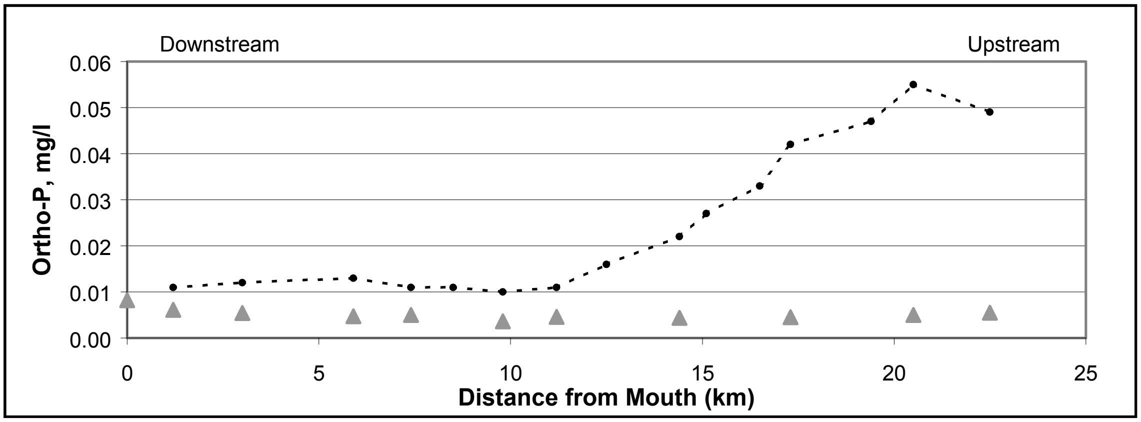


Figure A25: Ortho-Phosphate vs. River Mile for the Calibration of the Model (High flow)

▲ **Monitoring Data** _._._._._._._._. **Calibration**

Table A12: Ratio Dissolved Inorganic Nitrogen to Dissolved Inorganic Phosphorus

Segment	1	2	3	4	5	6	7	8
High Flow	104.3	116.1	259.1	259.0	254.4	262.0	213.0	183.9
Low Flow	40.3	77.1	115.2	198.1	152.5	124.5	67.2	44.0
Segment	9	10	11	12	13	14	15	
High Flow	160.4	158.7	161.0	162.1	126.9	100.2	116.0	
Low Flow	34.0	40.3	53.3	68.5	44.6	30.9	37.2	

Table A13: Nonpoint Source Concentrations for the Low Flow Baseline Condition Scenario

Segment Number	**NH4** *mg/l*	**NO_{23}** *mg/l*	**PO_4** *mg/l*	**CHL *a*** *$\mu g/l$*	**CBOD** *mg/l*	**DO** *mg/l*	**ON** *mg/l*	**OP** *mg/l*
11	0.1200	0.024	0.0027	82.00	7.3	7.0	1.300	0.1020
14	0.0435	0.049	0.0030	149.80	15.9	8.6	2.232	0.1968
15	0.0585	0.090	0.0040	163.91	19.6	8.9	2.361	0.2503
17	0.0680	0.196	0.0041	9.45	2.2	6.9	0.512	0.0272
19	0.0110	0.002	0.0025	47.60	7.2	9.0	0.951	0.0778
20	0.0380	0.031	0.0023	41.62	5.2	7.4	0.897	0.0739
21	0.0085	0.003	0.0034	65.50	7.5	7.5	1.270	0.1175
22	0.0085	0.003	0.0034	65.50	7.5	7.5	1.278	0.1175
23	0.1660	0.022	0.0027	39.25	11.4	7.2	1.902	0.1728
24	0.0190	0.017	0.0038	153.51	18.4	7.6	2.389	0.2358
26	0.0110	0.003	0.0022	39.50	6.8	7.6	0.963	0.0812
27	0.0675	0.019	0.0028	72.52	82	7.3	1.337	0.1084

Table A14: Point Source Loadings used in the Low Flow Baseline Condition Scenario, Average Baseline and TMDL Scenario

Parameter*	Betterton	Galena
Flow	757.1	302.8
NH_4	10.2284	0.1368
NO_{2-3}	1.1584	7.6654
PO_4	5.0499	1.8834
Chla	0.00	0.00
CBOD	6.7010	8.7206
DO	5.2234	1.6805
ON	2.2410	0.1499
OP	1.0069	0.5390

***All loadings in kg/day. Flow in m^3/day**

Table A15: Nonpoint Source Concentrations for the Average Flow Baseline Condition Scenario

Segment Number	NH4 *mg/l*	NO_{23} *mg/l*	PO_4 *mg/l*	CHL *a* *μg/l*	CBOD *mg/l*	DO *mg/l*	ON *mg/l*	OP *mg/l*
11	0.0850	0.3500	0.0100	82.00	7.4	6.0	0.4000	0.0500
14	0.0243	0.2715	0.0043	149.80	2.0	6.3	1.5465	0.1324
15	0.0240	0.4824	0.0057	163.91	3.0	5.3	1.7641	0.2020
17	0.0528	0.6047	0.0055	9.45	2.2	6.9	0.4465	0.0342
19	0.0220	0.3595	0.0028	47.60	7.2	9.0	0.7451	0.0625
20	0.0273	0.3215	0.0024	41.62	5.2	7.4	0.8034	0.0636
21	0.0110	0.2760	0.0031	65.50	7.5	7.5	1.0010	0.0868
22	0.0110	0.2760	0.0031	65.00	7.4	7.5	1.0010	0.0868
23	0.0792	0.2609	0.0036	39.25	11.4	7.2	1.3309	0.1174
24	0.0118	0.2492	0.0043	153.51	18.4	7.6	1.5482	0.1425
26	0.0130	0.2029	0.0026	39.50	6.8	7.6	0.9182	0.0762
27	0.0343	0.2664	0.0034	72.52	8.2	7.3	1.1458	0.0867

Baseline Condition Low Flow Scenario

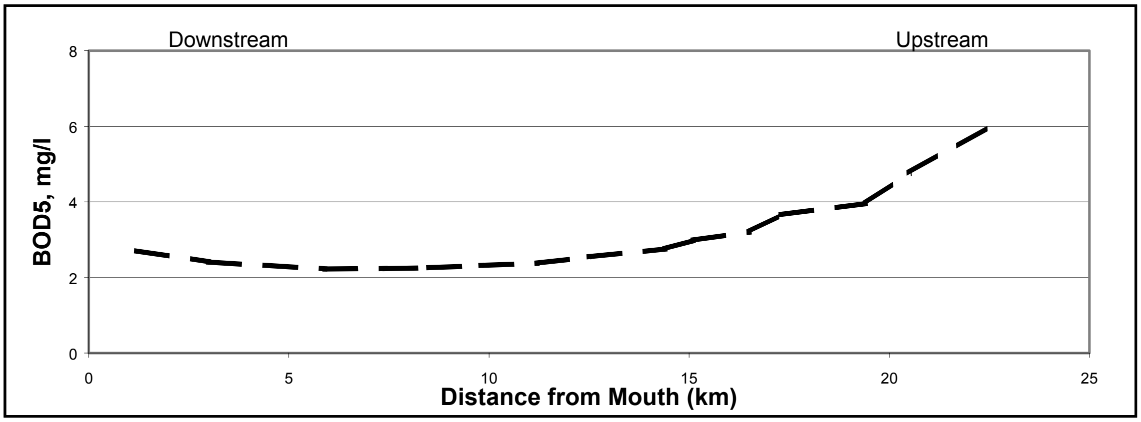


Figure A26: BOD vs. River Mile for the Baseline Condition Low Flow Scenario

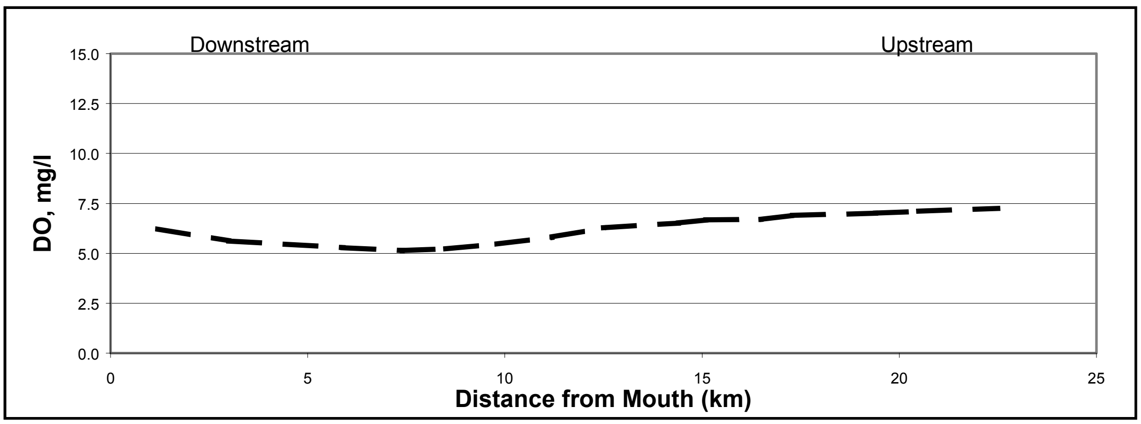


Figure A27: Dissolved Oxygen vs. River Mile for the Baseline Condition Low Flow Scenario

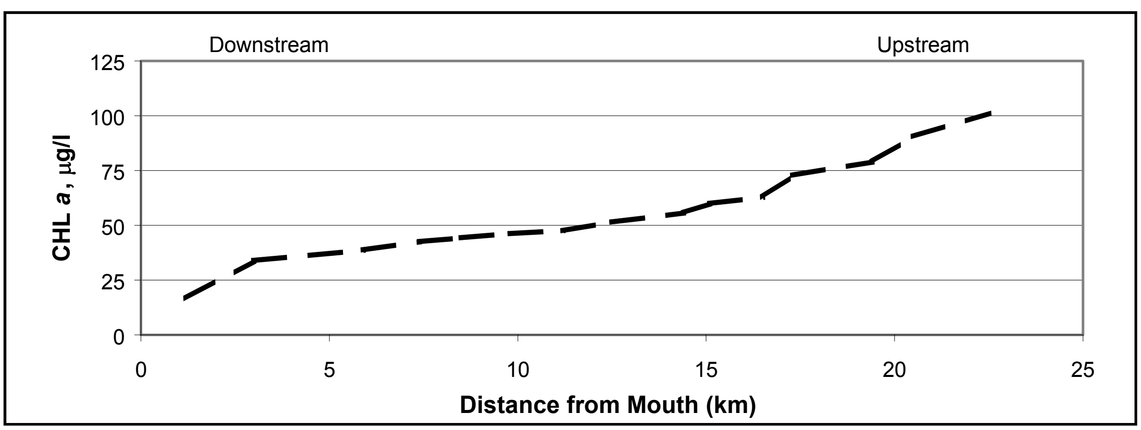


Figure A28: Chlorophyll *a* vs. River Mile for the Baseline Condition Low Flow Scenario

Baseline Condition Low Flow Scenario

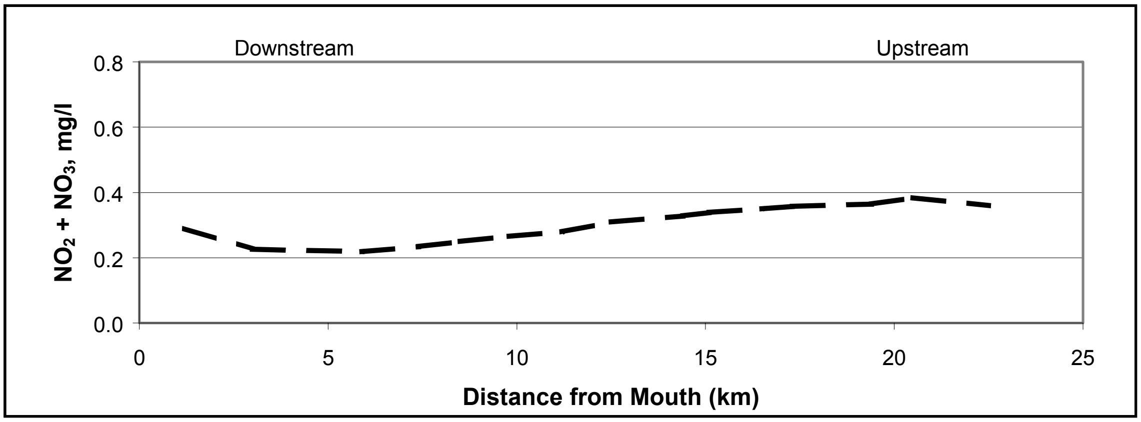


Figure A29: Nitrate (plus Nitrite) vs. River Mile for the Baseline Condition Low Flow Scenario

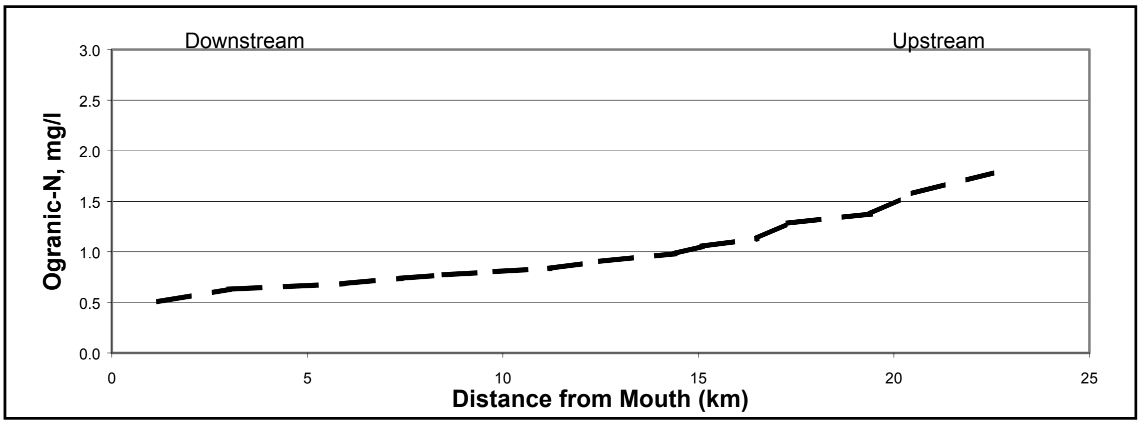


Figure A30: Organic Nitrogen vs. River Mile for the Baseline Condition Low Flow Scenario

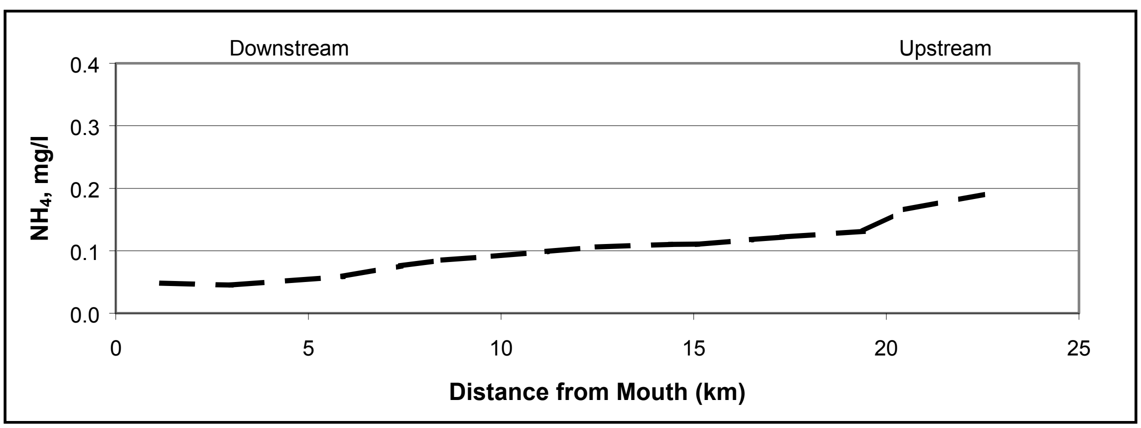


Figure A31: Ammonia vs. River Mile for the Baseline Condition Low Flow Scenario

— — — — Baseline Condition Low Flow Scenario

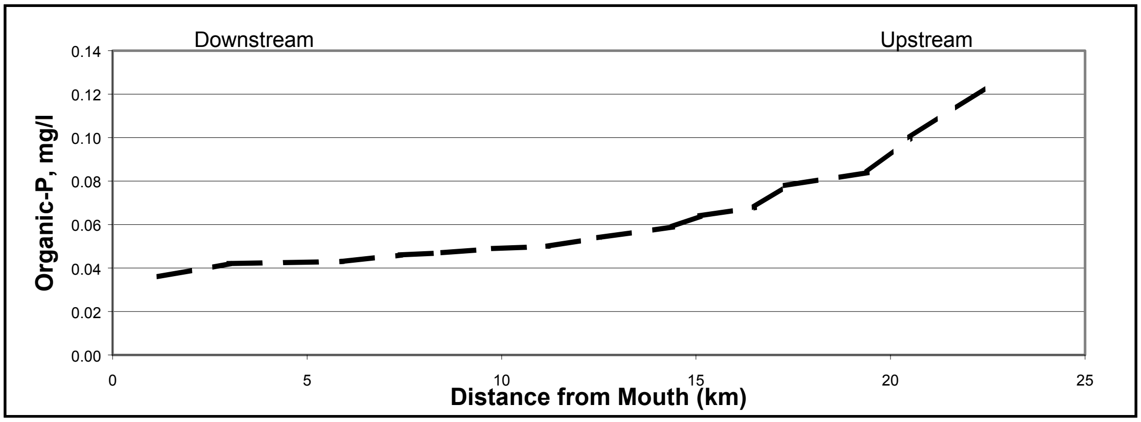


Figure A32: Organic Phosphorus vs. River Mile for the Baseline Condition Low Flow Scenario

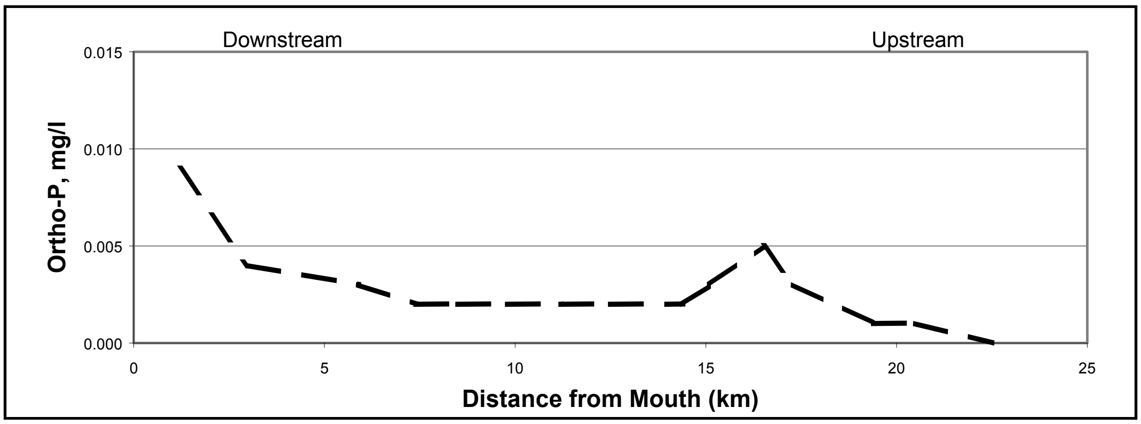


Figure A33: Ortho-Phosphorus vs. River Mile for the Baseline Condition Low Flow Scenario

— — — — Baseline Condition Low Flow Scenario

Baseline Condition Average Flow Scenario

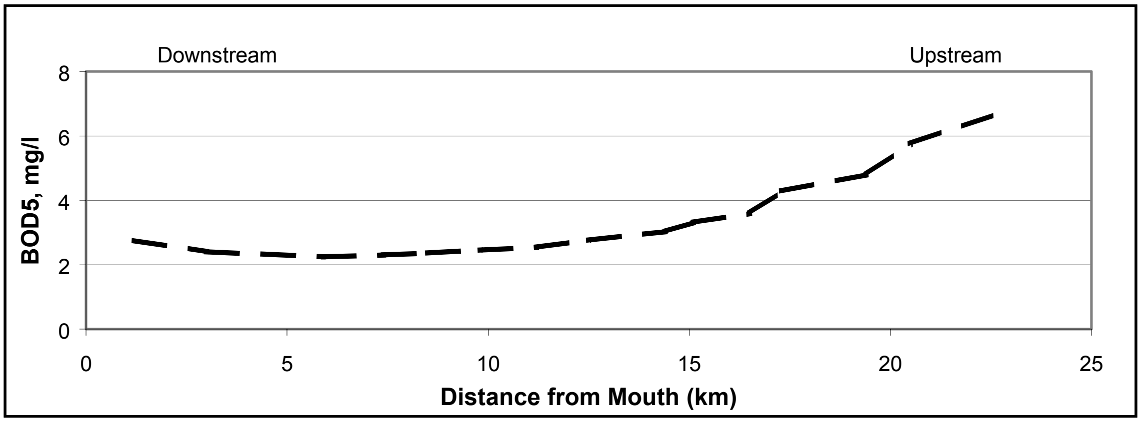


Figure A34: BOD vs. River Mile for the Baseline Condition Average Flow Scenario

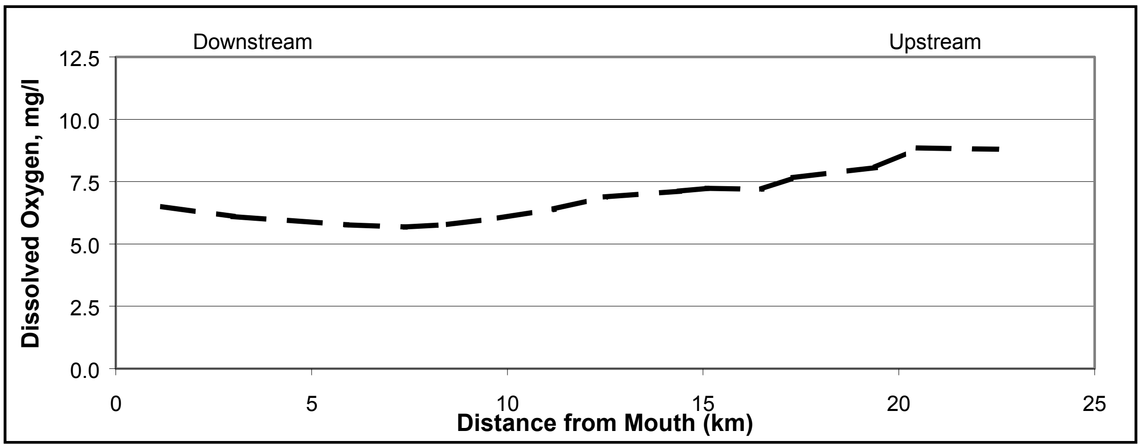


Figure A35: Dissolved Oxygen vs. River Mile for the Baseline Condition Average Flow Scenario

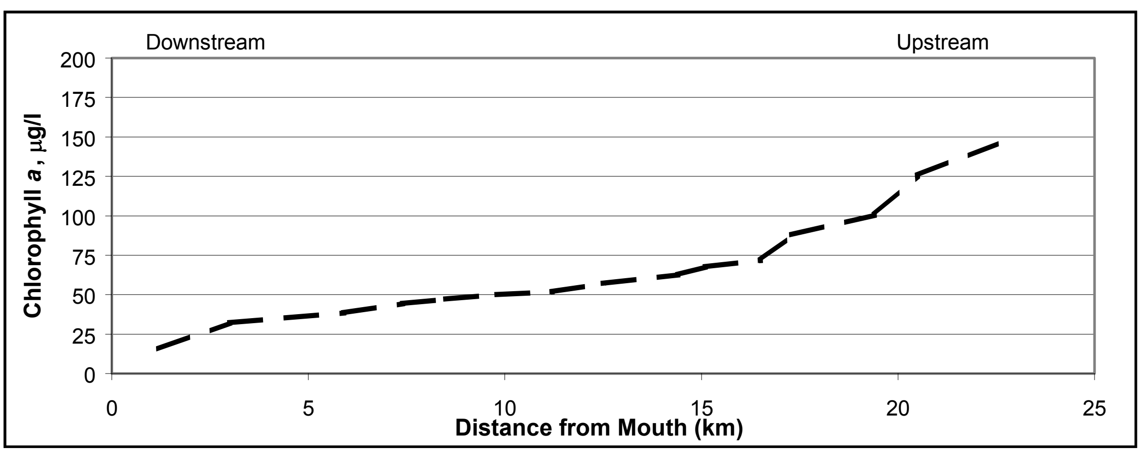


Figure A36: Chlorophyll *a* vs. River Mile for the Baseline Condition Average Flow Scenario

Baseline Condition Average Flow Scenario

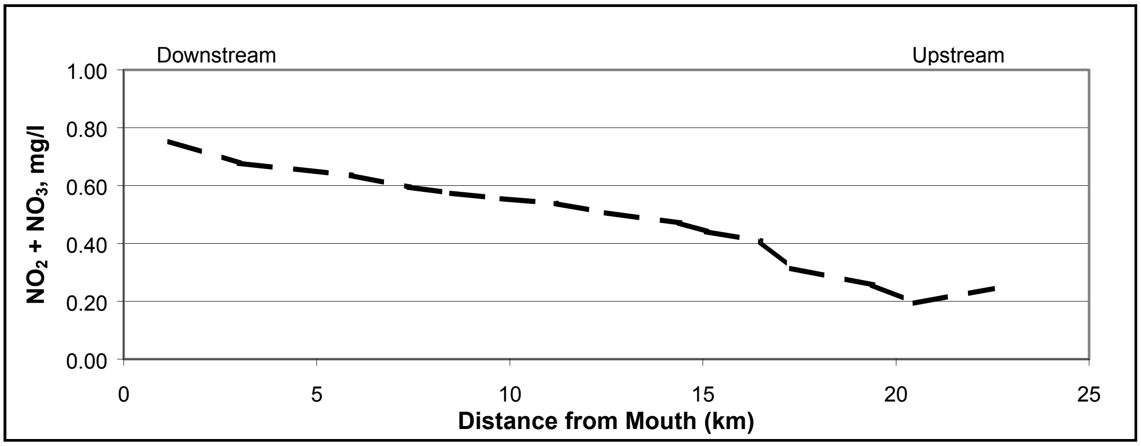


Figure A37: Nitrate (plus Nitrite) vs. River Mile for the Baseline Condition Average Flow Scenario

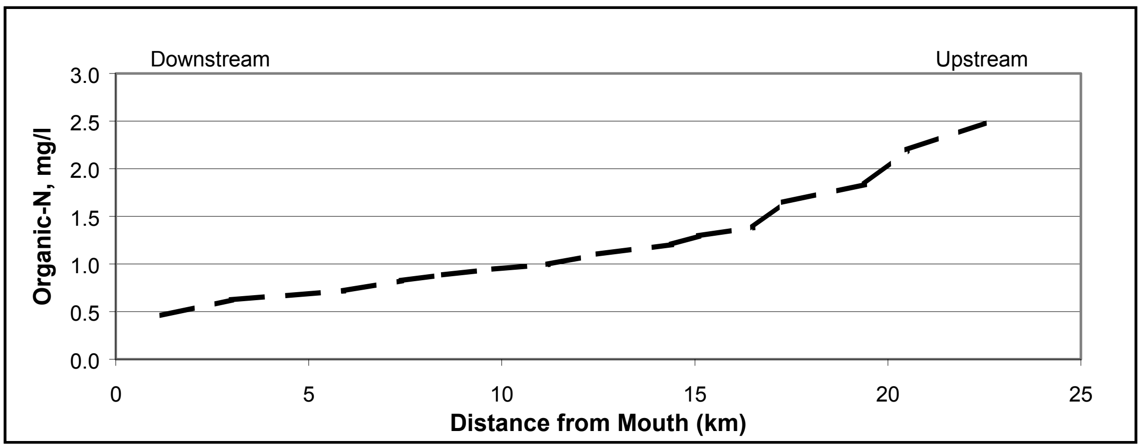


Figure A38: Organic Nitrogen vs. River Mile for the Baseline Condition Average Flow Scenario

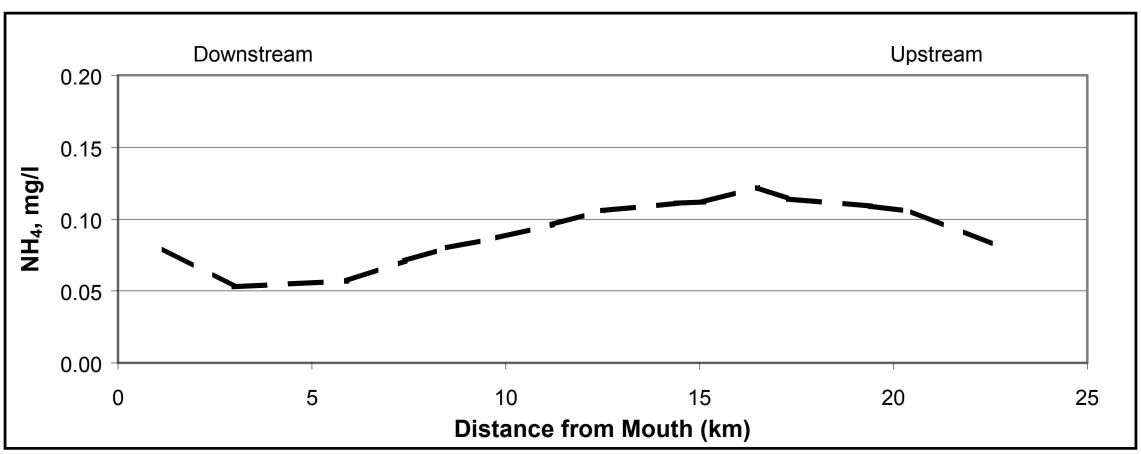


Figure A39: Ammonia vs. River Mile for the Baseline Condition Average Flow Scenario Baseline Condition Average Flow Scenario

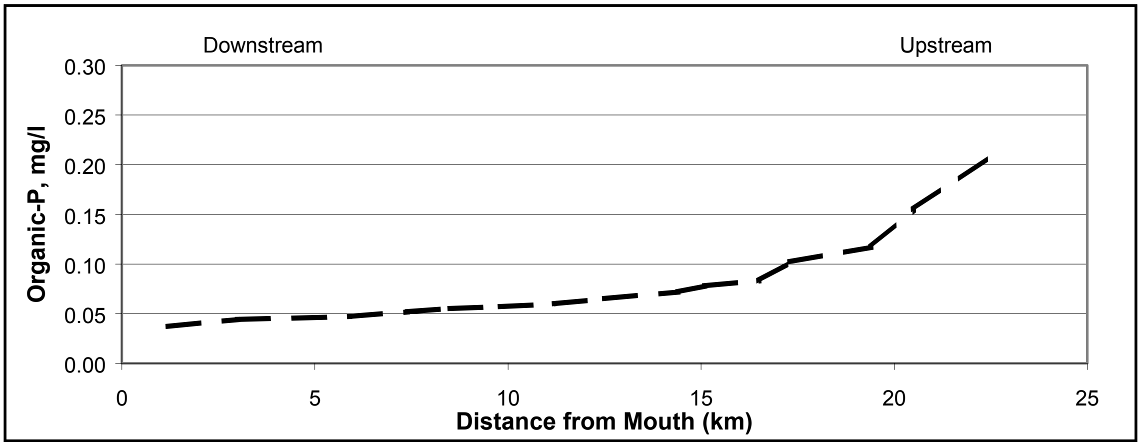


Figure A40: Organic Phosphorus vs. River Mile for the Baseline Condition Average Flow Scenario

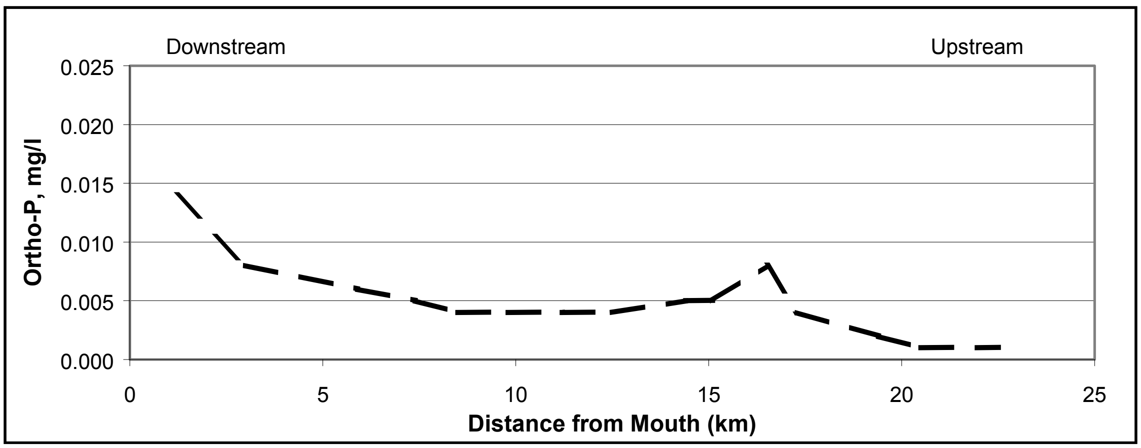


Figure A41: Ortho-Phosphorus vs. River Mile for the Baseline Condition Average Flow Scenario

\- - - - - - **Baseline Condition Average Flow Scenario**

Table A16: Nonpoint Source Concentration for the Low Flow Future Condition Scenario

Segment Number	NH4 mg/l	NO_{23} mg/l	PO4 mg/l	CHL *a* µg/l	CBOD mg/l	DO mg/l	ON mg/l	OP mg/l
11	0.1200	0.0240	0.0016	49.2	7.3	7	1.3000	0.0581
14	0.0435	0.0490	0.0012	67.4	15.9	8.6	2.2320	0.1108
15	0.0585	0.0900	0.0017	73.8	19.6	8.9	2.3610	0.1421
17	0.0680	0.1960	0.0023	5.7	2.2	6.9	0.5120	0.0152
19	0.0110	0.0020	0.0015	28.6	7.2	9	0.9510	0.0437
20	0.0380	0.0310	0.0013	25.0	5.2	7.4	0.8970	0.0426
21	0.0085	0.0030	0.0020	39.3	7.5	7.5	1.2700	0.0669
22	0.0085	0.0030	0.0020	39.3	7.5	7.5	1.2780	0.0662
23	0.1660	0.0220	0.0016	23.6	11.4	7.2	1.9020	0.1001
24	0.0190	0.0170	0.0017	69.1	18.4	7.6	2.3890	0.1365
26	0.0110	0.0030	0.0012	23.7	6.8	7.6	0.9630	0.0455
27	0.0675	0.0190	0.0014	43.5	82	7.3	1.3370	0.0572

Table A17: Nonpoint Source Concentration for the Average Flow Future Condition Scenario

Segment Number	NH4 mg/l	NO_{23} mg/l	PO_4 mg/l	CHL *a* µg/l	CBOD mg/l	DO mg/l	ON mg/l	OP mg/l
11	0.0850	0.3500	0.00612	49.2	7.4	6	0.4000	0.03102
14	0.0243	0.2715	0.00211	44.9	2	6.3	1.5465	0.06410
15	0.0240	0.4824	0.00278	49.2	3	5.3	1.7641	0.09690
17	0.0528	0.6047	0.00341	5.7	2.2	6.9	0.4465	0.02144
19	0.0220	0.3595	0.00172	28.6	7.2	9	0.7451	0.03908
20	0.0273	0.3215	0.00147	25.0	5.2	7.4	0.8034	0.03915
21	0.0110	0.2760	0.00190	39.3	7.5	7.5	1.0010	0.05385
22	0.0110	0.2760	0.00190	39.0	7.4	7.5	1.0010	0.05420
23	0.0792	0.2609	0.00220	23.6	11.4	7.2	1.3309	0.07208
24	0.0118	0.2492	0.00200	76.8	18.4	7.6	1.5482	0.06687
26	0.0130	0.2029	0.00169	23.7	6.8	7.6	0.9182	0.04773
27	0.0343	0.2664	0.00225	43.5	8.2	7.3	1.1458	0.05618

Future Low Flow TMDL Scenario Results

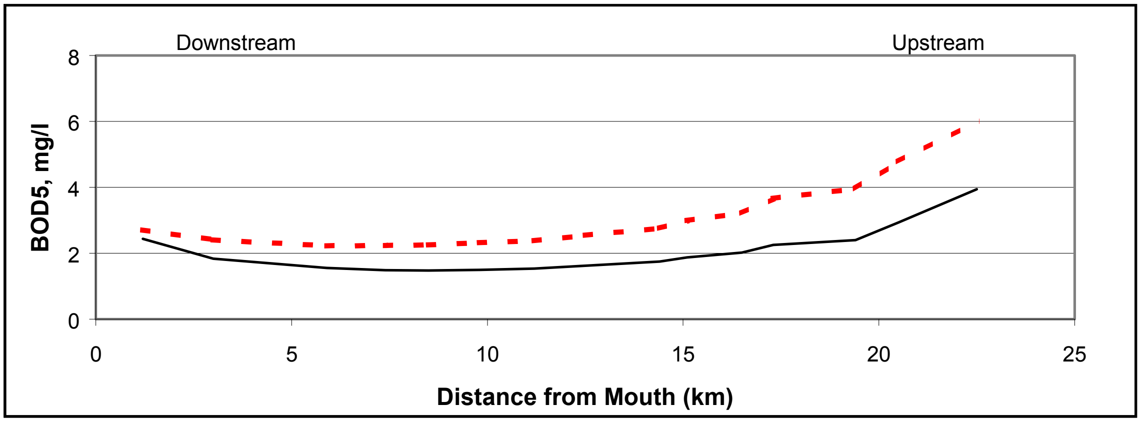


Figure A42: BOD vs. River Mile for the Future Low flow TMDL scenario

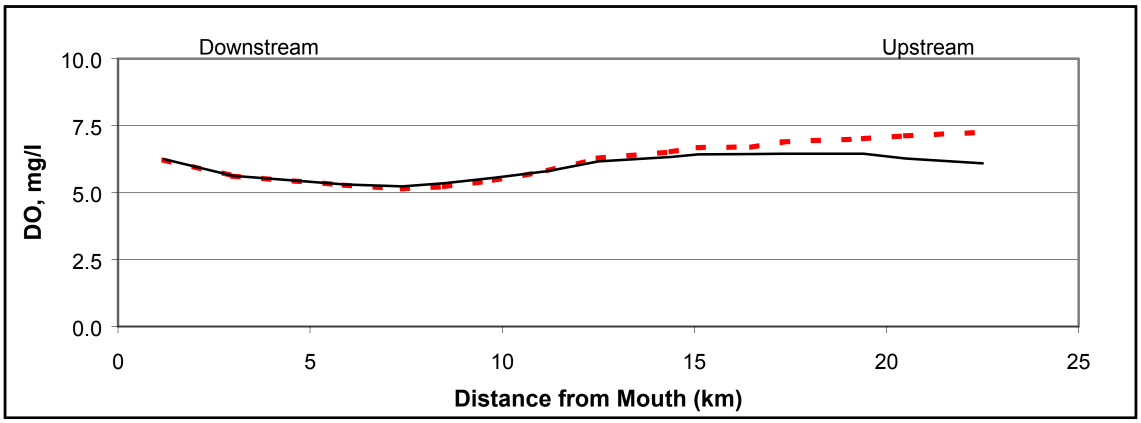


Figure A43: Dissolved Oxygen vs. River Mile for the Future Low Flow TMDL Scenario

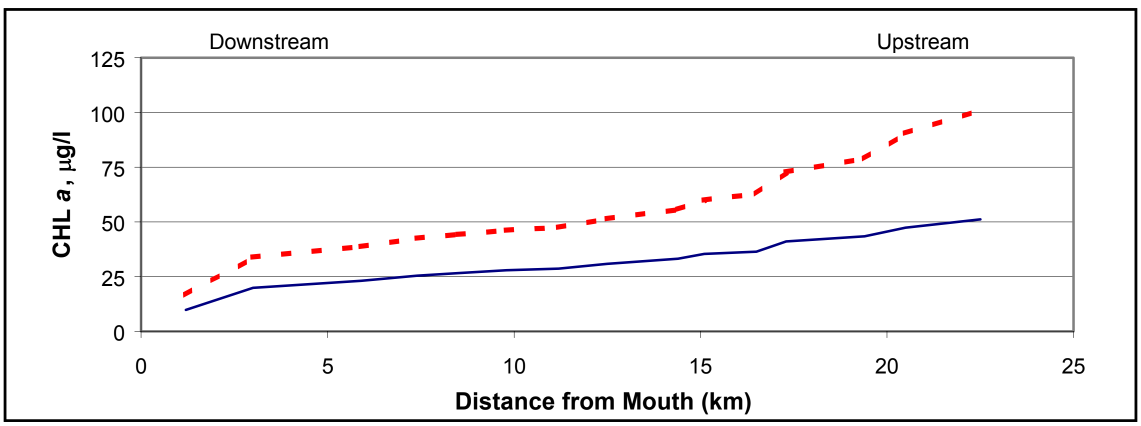


Figure A44: Chlorophyll *a* vs. River Mile for the Future Low Flow TMDL scenario

Baseline Condition Low Flow Scenario **Future Low Flow TMDL Scenario**

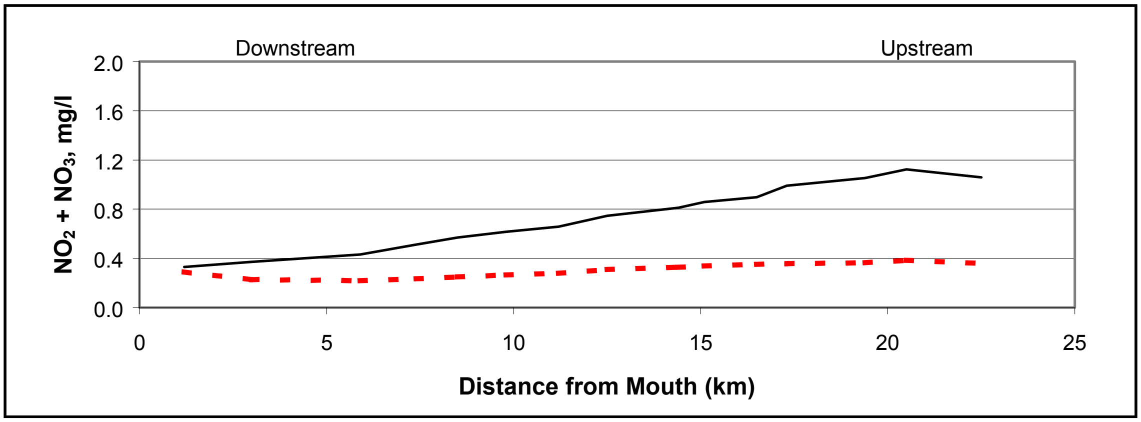


Figure A45: Nitrate (plus Nitrite) vs. River Mile for the Future Low flow TMDL Scenario

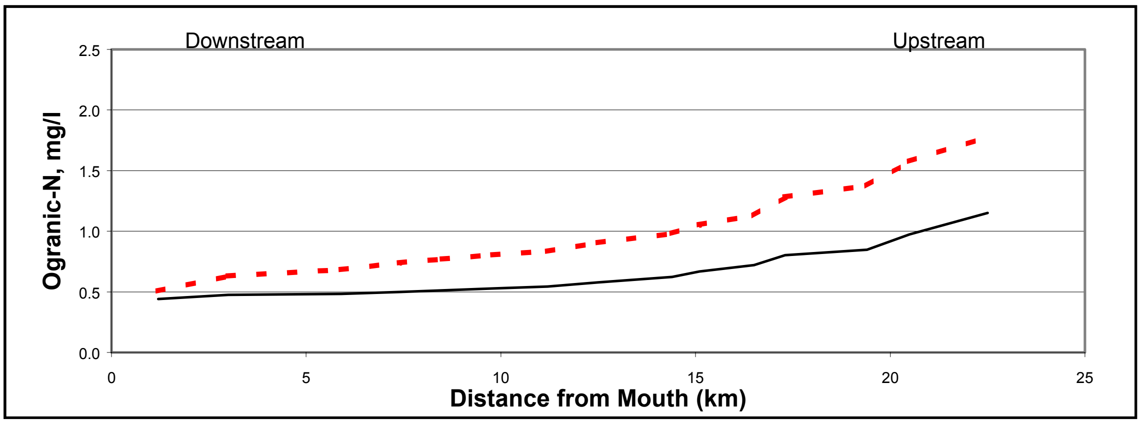


Figure A46: Organic Nitrogen vs. River Mile for the Future Low Flow TMDL Scenario

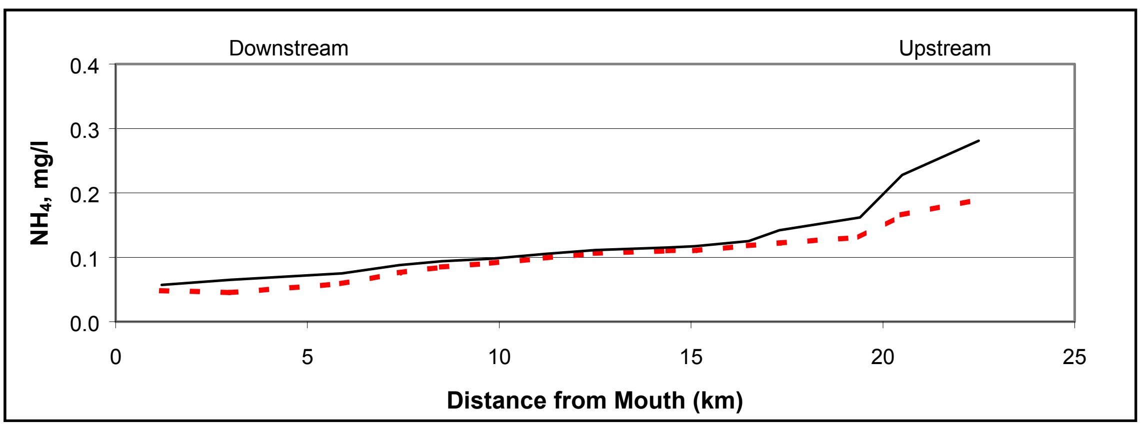


Figure A47: Ammonia vs. River Mile for the Future Low Flow TMDL Scenario

Baseline Condition Low Flow Scenario **Future Low Flow TMDL Scenario**

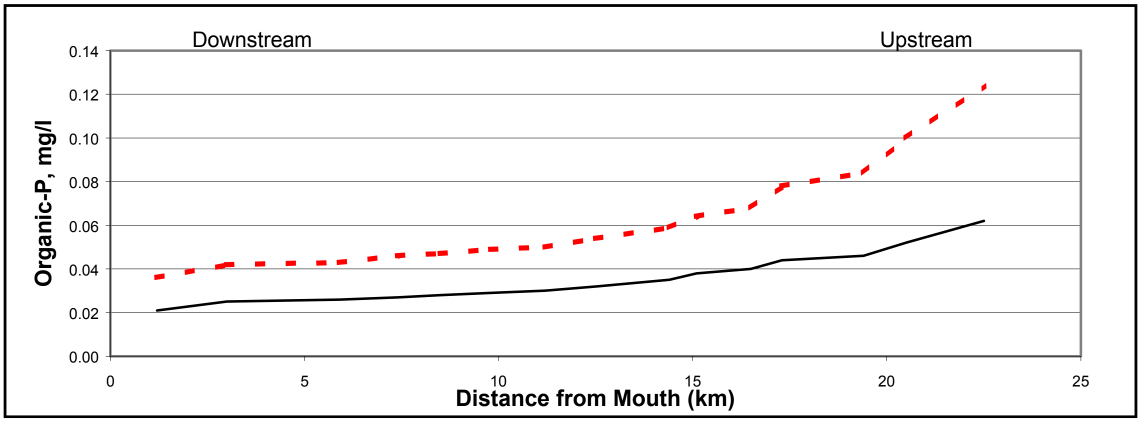


Figure A48: Organic Phosphorus vs. River Mile for the Future Low Flow TMDL Scenario

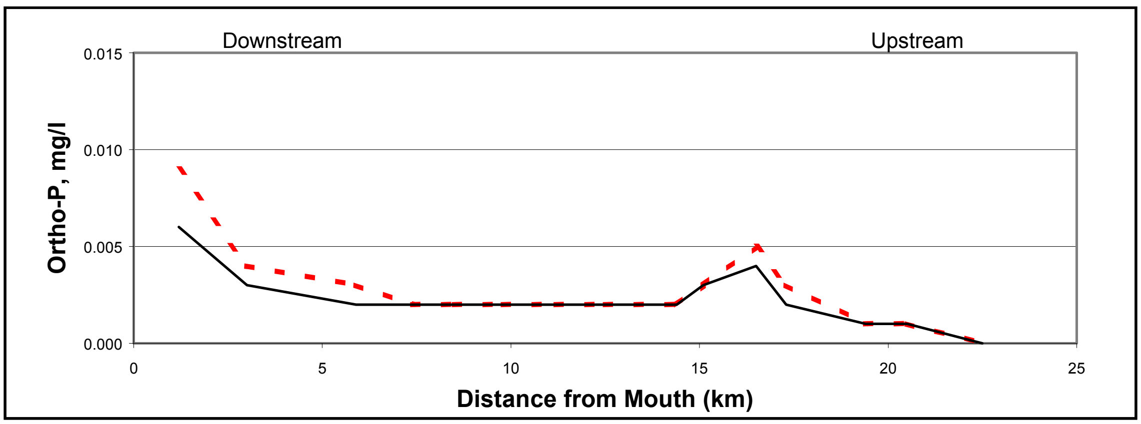


Figure A49: Ortho-Phosphate vs. River Mile for the Future Low Flow TMDL Scenario

Baseline Condition Low Flow Scenario **Future Low Flow TMDL Scenario**

Future Average Flow TMDL Scenario Results

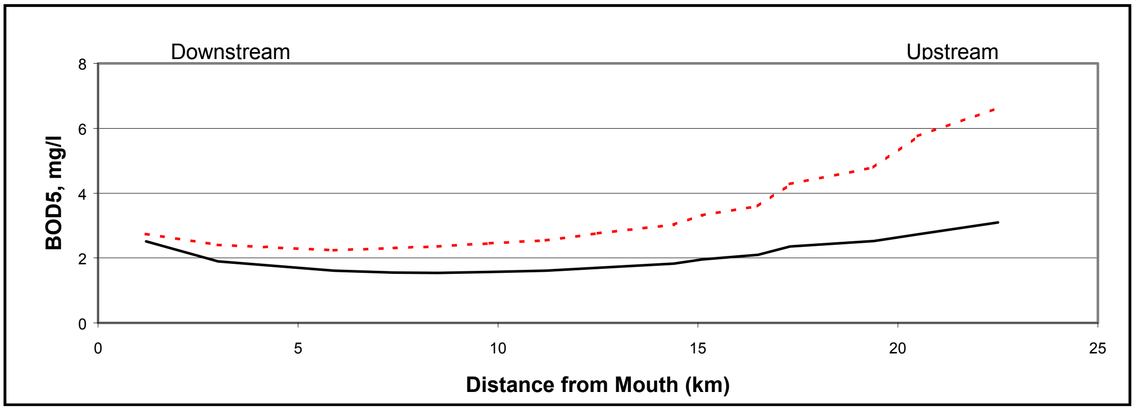


Figure A50: BOD vs. River Mile for the Future Average Flow TMDL scenario

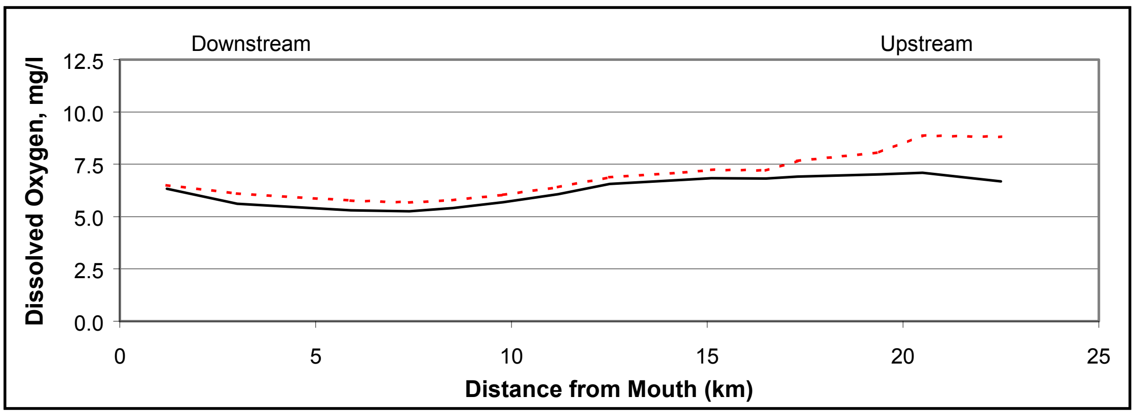


Figure A51: Dissolved Oxygen vs. River Mile for the Future Average Flow TMDL Scenario

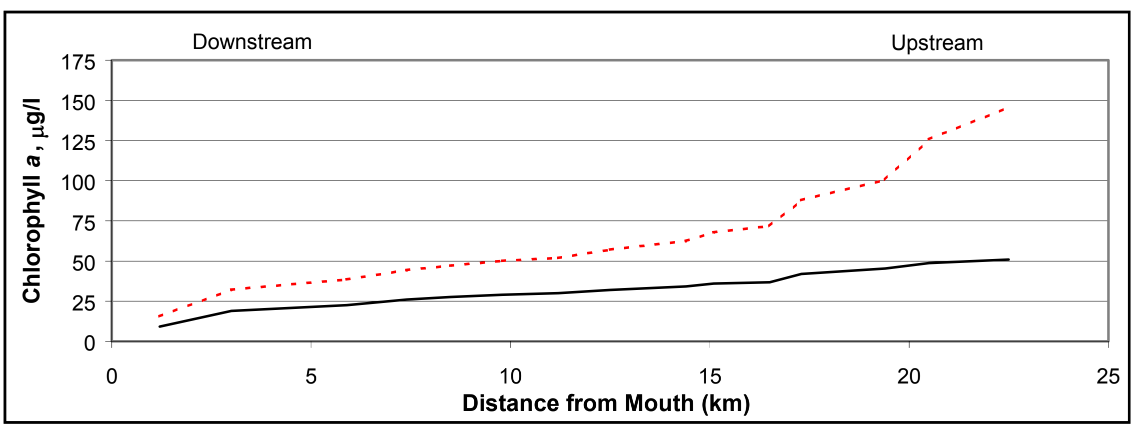


Figure A52: Chlorophyll *a* vs. River Mile for the Future Average Flow TMDL scenario

Average Flow Baseline Condition Scenario
Future Average Flow TMDL Scenario

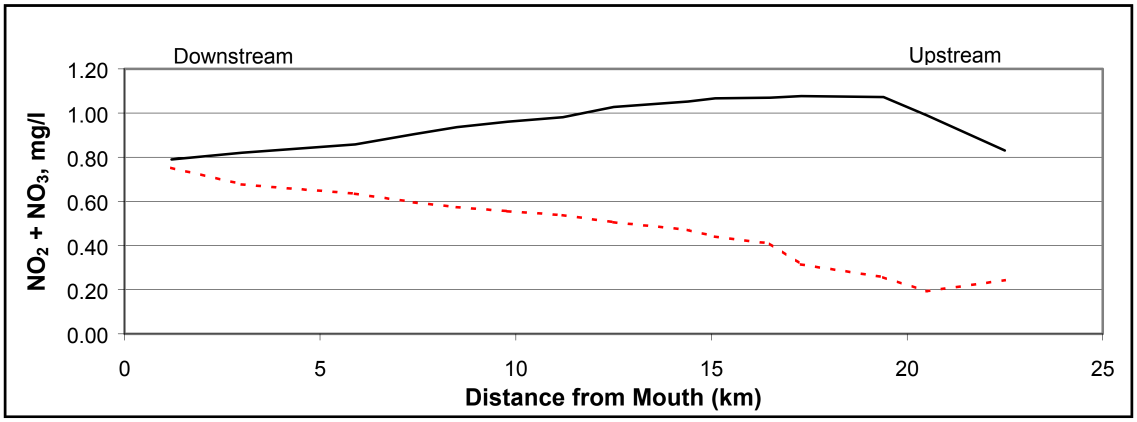


Figure A53: Nitrate (plus Nitrite) vs. River Mile for the Future Average Flow TMDL Scenario

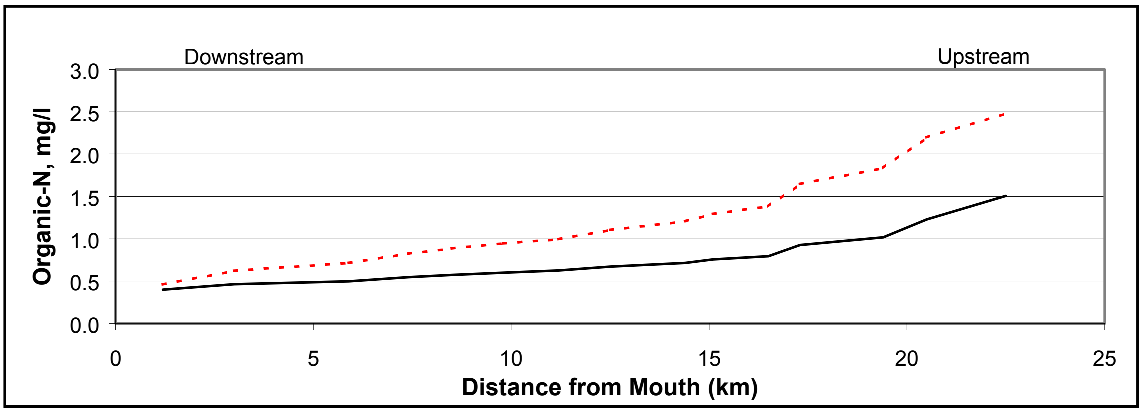


Figure A54: Organic Nitrogen vs. River Mile for the Future Average Flow TMDL Scenario

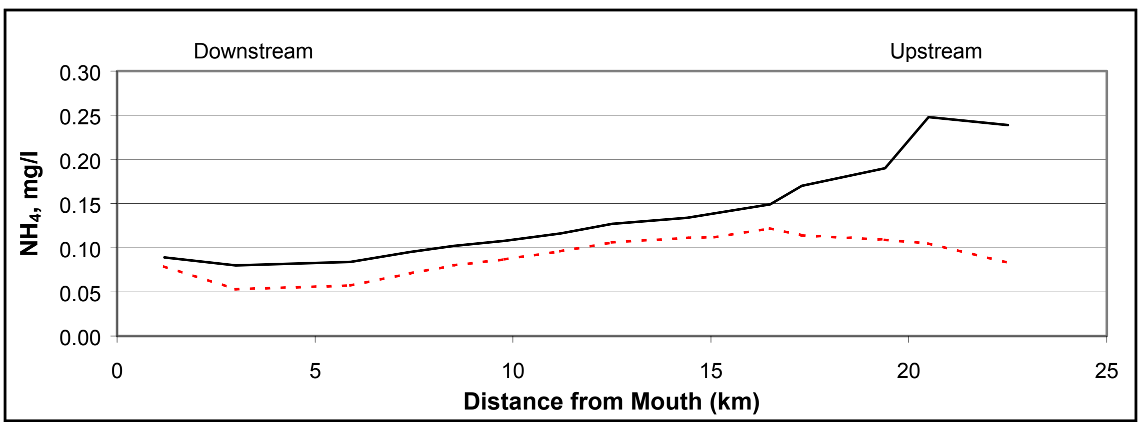


Figure A55: Ammonia vs. River Mile for the Future Average Flow TMDL Scenario

Average Flow Baseline Condition Scenario
Future Average Flow TMDL Scenario

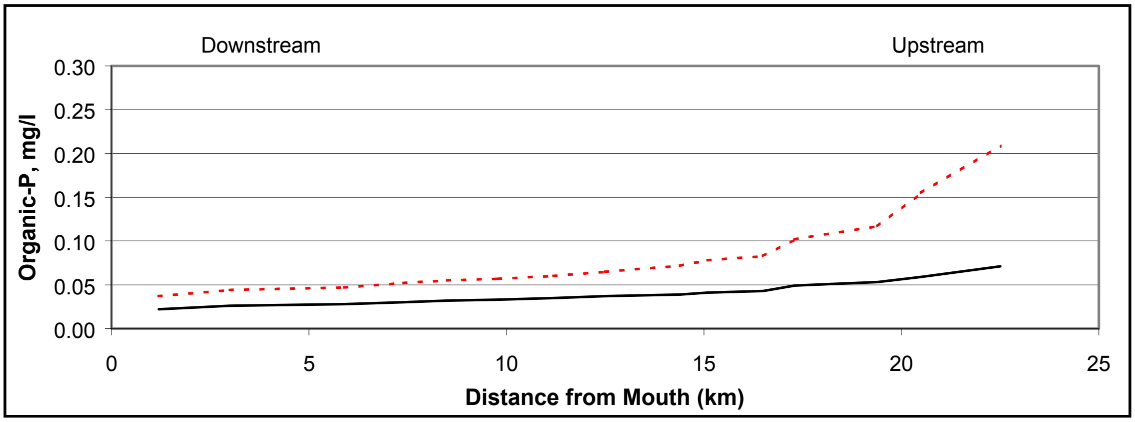


Figure A56: Organic Phosphorus vs. River Mile for the Future Average Flow TMDL Scenario

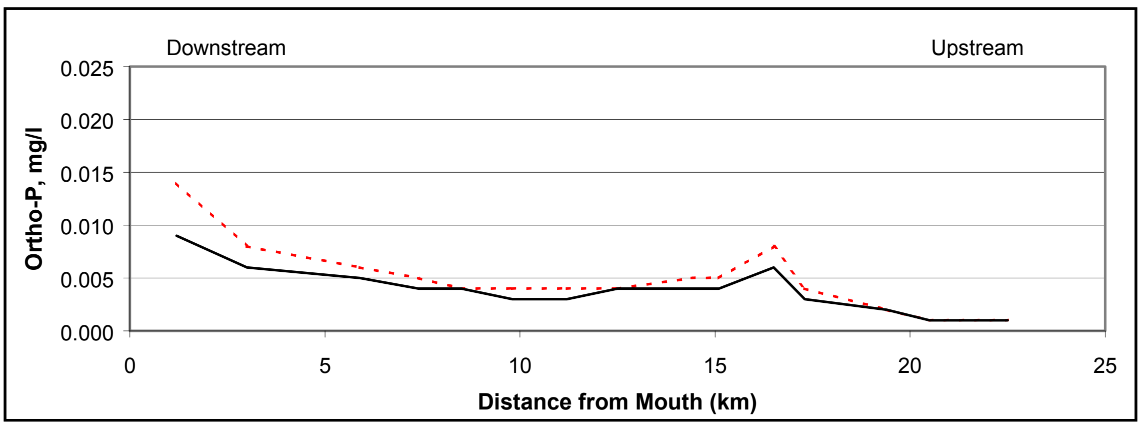


Figure A57: Ortho-Phosphate vs. River Mile for the Future Average Flow TMDL Scenario

Average Flow Baseline Condition Scenario
Future Average Flow TMDL Scenario

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