APPENDIX A

Total Maximum Daily Load of Biochemical Oxygen Demand (BOD) for The Western Branch of the Patuxent River

DESCRIPTION AND SETTING

The Western Branch River, a tributary of the Patuxent River, is located in Prince George's County, Maryland. The River is approximately 32 kilometers in length along the mainstem. The watershed of the Western Branch has an area of approximately 290 square kilometers or 71,420 acres. The predominant land use in the watershed is forest (126 km^2 or 44%) with some urban (89 km^2 or 31%) and mixed agricultural (74 km^2 acres or 25%). The upper free-flowing portion of the Western Branch traverses through urban and forest lands. The lower, tidal portion enters the Patuxent River near Mt. Calvert in the oligohalene salinity zone. Much of the Western Branch's tidal portion is classified as piedmont shallow fresh marsh. Depths of the river range from about 1/3 to 2/3 of a meter in the headwaters, to about 1 meter in the tidal zone prior to the river's confluence with the Patuxent River.

The upper portion of the Western Branch watershed traverses through steep slopes with medium to high stream velocities. The lower portion below Upper Marlboro is a slow flowing system. The lower portion of the drainage basin is generally flat, and the soils are typically classified as sandy or loamy. As a consequence of the generally flat topography and the sandy soils, stream velocities in this portion of the river are minimal. Tidal currents in the lower river are extremely weak and variable. A diffuse head of tide is located near the Route 301 bridge below Upper Marlboro. Bottom sediments in the river are typically found to be firm muds and clays of moderate to high compaction, locally mixed with sand and other deposits.

WATER QUALITY CHARACTERIZATION

Two historical water quality sampling stations, WXT0001 and WXT0045, were used to characterize the water quality in the Western Branch. Figure A1 shows the location of the water quality sampling sites, a USGS flow gage, and other geographic points of reference in the watershed. Measurements of the physical and chemical samples have been taken since September 1985 at station WXT0045 and since September 1990 at station WXT0001. The physical and chemical samples were taken by the Maryland Department of Natural Resources and the Maryland Department of the Environment. The physical parameters like dissolved oxygen and water temperature were measured *in situ* at each water chemistry monitoring station. Grab samples were collected for chemical and nutrient analysis. The samples were collected at a depth of 0.5 m from the surface. Samples were placed in plastic bottles and preserved on ice until they were delivered to the Department of Health and Mental Hygiene in Baltimore, MD for chemical analysis. The field and laboratory protocols used to collect and process the samples are also described in Table A1.

Dissolved oxygen, chlorophyll *a*, dissolved inorganic nitrogen (ammonia + nitrite + nitrate), organic nitrogen, dissolved inorganic phosphorus, and organic phosphorus were examined, for the period between August 1990 and December 1998, to determine the extent of the impairment in the Western Branch. Figure A2 shows the measured dissolved oxygen concentrations at the water quality station

WXT0001, downstream from the Western Branch Wastewater Treatment Plant (WWTP). As can be seen the dissolved oxygen level goes below 5 mg/l occasionally during this period. As recently as June 1998, the dissolved oxygen level fell to within 0.2 mg/l of the water quality standard. There is no problem with low dissolved oxygen concentrations during winter months. Figure A3 shows the chlorophyll *a* concentrations at station WXT0001. It can be seen that the concentration peaks to around 70 μg/l during the summer.

Figure A4 shows the dissolved inorganic nitrogen at the water quality station WXT0045. The figure shows that in general dissolved inorganic nitrogen levels average about 0.5 mg/l, with one peak as high as 4.0 mg/l. Figure A5 shows the organic nitrogen concentrations for the same water quality monitoring station. The organic nitrogen levels average around 0.8 mg/l.

Figure A6 shows the dissolved inorganic phosphorus concentrations at station WXT0045. It can be seen that in general the dissolved inorganic phosphorus concentrations vary between 0.005 and 0.06 mg/l. Figure A7 shows the organic phosphorus concentrations at the same water quality station. The organic phosphorus concentrations average around 0.08mg/l.

MODELING FRAMEWORK

The computational framework chosen for the TMDL of Western Branch was the Water Quality Analysis Simulation Program 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 studying time-variable or steady-state, one, two or three dimensional, linear or non-linear kinetic water quality problems. To date, WASP has been employed in many modeling applications that have included river, lake, estuarine and ocean environments, and the model has been used to investigate dissolved oxygen, eutrophication, and toxic substance problems. WASP has been used in a wide range of applications by regulatory agencies, consulting firms, 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 to modeling eutrophication, incorporating eight water quality constituents in the water column (Figure A8) and sediment bed. EUTRO5.1 is used to develop the water quality model of the Western Branch system.

INPUT REQUIREMENTS[1]

Model Segmentation and Geometry

The spatial domain of the Western Branch Eutrophication Model (WBEM) extends from the confluence of the Western Branch and the Patuxent River for about 5.6 kilometers upstream along the mainstem of the Western Branch to station WXT0045. Following a review of the bathymetry for the Western Branch River, the model was divided into 10 segments. Table A2 lists the volumes, characteristic lengths and interfacial areas of the 10 segments. Station WXT0045 is considered the upper boundary of the model's spatial domain. Charles Branch is a tributary that flows into the Western Branch just before its confluence with the Patuxent.

There are three National Pollutant Discharge Elimination System (NPDES) point sources in the modeling domain. The only direct point source is the Western Branch WWTP. The other two point sources are the Croom Manor Housing WWTP, and the Prince George's County Yardwaste Composting Facility. Both of these facilities eventually discharge into the Charles Branch. Figure A9 shows the model segmentation, the location of the upper boundary at station WXT0045, the Western Branch WWTP, and Charles Branch.

Freshwater Flows

The freshwater flows used in the model were obtained from the USGS gage located in Upper Marlboro (01594526). This gage was assumed to represent all the flow coming from the upper portion of the Western Branch watershed. Data has been collected at that station since October 1985, with data missing from May 1989 to March 1992. A statistical analysis was performed on the flow data and representative summer low flow and winter low flow months were selected for use with the model scenario runs. There is no flow gage on the Charles Branch. Flow was calculated as a portion of the flow recorded at USGS gage 01594526, based on relative drainage area size. Flow data, collected by Maryland Department of the Environment's (MDE) Field Operations Program staff in December 1997, were used for the calibration of the model (Table A3).

Point and Nonpoint Source Loadings

Three point sources were addressed in the development of the WBEM. The only direct point source discharge into the system was the Western Branch WWTP. The other two point sources flow into Charles Branch. The first was the Croom Manor Housing WWTP. To be conservative, it was assumed that the flow from both Croom Manor and the composting facility were

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

discharging directly into the Western Branch at the same location as Charles Branch. The loadings for all point sources were calculated as the flow multiplied by the concentration. Prince George's County Yardwaste Composting Facility has an individual stormwater permit. It will only discharge loads during rainfall events.

Nonpoint source loads enter the system at two locations. The first nonpoint source load enters the model at the upper boundary (station WXT0045) corresponding to model segment 1. This load accounts for all inputs draining from the upper part of the Western Branch drainage basin. The second nonpoint source load comes from the Charles Branch, and enters the model at segment 8.

The entire upper watershed of the Western Branch is assumed to drain into segment 1 of the model. All of Charles Branch, Croom Manor Housing WWTP, and Prince George's County Yardwaste Composting Facility are assumed to drain into model segment 8. The Western Branch WWTP is assumed to discharge into model segment 5.

Environmental Conditions

For application of the EUTRO model to the Western Branch, four environmental parameters were used: solar radiation, photoperiod, temperature, and light extinction coefficient.

Environmental Parameters

Parameter	Value
Solar radiation (*langleys / day*)	750.0
Photoperiod (fraction of a day)	0.6
Temperature (^oC)	14.3
Light extinction coefficient (m^{-1})	6.8

Initial exchange coefficients were obtained from previous modeling of the Western Branch and adjusted during the calibration of the model. Final values were 0.1m^2/day for segments 1 and 2; 1.0 m^2/day for segments 2 through 4; 3.0 m^2/day for segments 4 through 6; 5.0 m^2/day for segments 6 through 9; and 17.25 m^2/day for segments 9 and 10.

Kinetic Coefficients

The water column kinetic coefficients are universal constants used in the EUTRO5 model. They are formulated to characterize the kinetic interactions among the water quality constituents. The initial values were taken from past modeling studies of the Potomac (Thomann and Fitzpatrick, 1982, Cerco, 1985, Panday and Haire, 1986, Domotor *et al*., 1987), and the Patuxent (Lung, 1993). The kinetic coefficients are listed in Table A5.

A phytoplankton settling rate velocity of 0.229 *m/day* was used following a series of model calibration and sensitivity runs. Nonliving organic nutrient components settle from the water column into the sediment at a settling rate velocity of 0.186 *m/day*. In general, 50% of the nonliving organics were considered in the particulate form. Initial values were taken from previous modeling studies, and later refined through model sensitivity analyses.

Initial Conditions

The initial conditions used in the model were as close to the observed values as possible. Model runs indicate that steady state conditions were obtained after 10 days.

CALIBRATION & SENSITIVITY ANALYSIS

The EUTRO5.1 model was calibrated with December 1997 data. The point source flows and concentrations for the Western Branch WWTP that were used in the calibration of the model were obtained from the Discharge Monitoring Reports (DMRs) Database, for December 1997. In December 1997, the Croom Manor Housing WWTP was under renovation. Site inspectors estimated that the facility was discharging at half its design flow. The concentrations at the plant were estimated from typical values seen at other small WWTPs. The loadings for both WWTPs were calculated as the flow multiplied by the concentration.

The nonpoint source loads entering the upper boundary of the model were water quality concentrations, collected by MDE's Field Operations Program staff at station WXT0045 in December of 1997 multiplied by the corresponding freshwater flow. Nonpoint source loads from the Charles Branch for BOD_5, dissolved oxygen, ammonia, and organic nitrogen represented average concentrations over the months of December through March for various water quality monitoring stations located in the Western Branch watershed and nearby Patuxent River/ Rt. 214 to Ferry Landing watershed. Winter values for nitrate, ortho-phosphate, and organic phosphorus were estimated with yearly averages because monthly data was not available. Included in the Charles Branch nonpoint source load were the loads from the Prince George's County Composting Facility. A flow-weighted average was taken on the loads coming from the Charles Branch and the Prince George's County Composting Facility. Concentrations at the composting facility were based on quarterly BOD_5 values recorded at that location from 7/1/96 to 9/30/96. Organic nitrogen and organic phosphorus were calculated as a percentage of the BOD_5 value and the ammonia, nitrate, and ortho-phosphate concentrations, were assumed proportional to organic nitrogen and organic phosphorus based on percentages found in pure compost (Bezdicek and Fauci, 1997). The flow at the composting facility was based on the average of quarterly discharge monitoring reports for the quarters ending in December for the years 1996 and 1997. Table A3 and Table A4 show the point and nonpoint source data associated with the calibration input file.

Figure A10 – A17 show the results of the calibration of the model. As can be seen in Figure A11 the model did a good job of capturing the trend in the dissolved oxygen data although it did not capture the peak values. The model did an excellent job of capturing the trend in the biochemical oxygen demand (BOD) (Figure A10). The model also did a good job of replicating the organic nitrogen and organic phosphorus concentrations as well as their overall trend (Figure A14 and A16). It was able to replicate the nitrate and ortho-phosphate trends although it did not capture the peak values because of the spread in the data (Figure A13 and A17).

Sensitivity analyses were conducted for the major parameters that affect dissolved oxygen in the model kinetics. Four parameters were examined, the sediment oxygen demand (SOD), the reaeration coefficient, the carbonaceous biochemical oxygen demand (CBOD) decay rate and the nitrification rate. The SOD used in the model was 0.5 g/m^2 day, which is considered on the lower end of possible values for this parameter. To test the sensitivity of the model, the SOD was increased to 1 then to 2-g/m^2 day. This had a minimal effect on the calibration of the model. At the maximum deviation from the model value, the minimum DO concentration was only reduced by 16 %.

The reaeration coefficient used in the model was 0.5 day^{-1}. To test the sensitivity of the model, the reaeration coefficient was decreased to 0.2 day^{-1} and then increased to 1.0 day^{-1}. Neither value significantly changed the minimum DO concentration.

The CBOD decay rate used in the model was 0.20 day^{-1}. Previous modeling of Gunston Cove and Mattawoman Creek used a CBOD decay rate of 0.10 day^{-1}. When this value was used in the calibration of the model, the DO concentration did not significantly increase. When the decay rate was increased to 0.30 day^{-1}, again the DO concentration did not significantly change.

The final parameter was the nitrification rate. The value used in the model was 0.08 day^{-1}. Previous modeling of the Potomac River used values in the range of 0.09 to 0.13 day^{-1}. To test the sensitivity of the model, the nitrification rate was increased to 0.13 day^{-1}. There was a minimal effect on the calibration of the model.

The model was post-audited with summer data provided by the Washington Suburban Sanitary Commission (WSSC) (Russell). The post-audit was performed to verify that the WBEM, which was calibrated during winter, could accurately predict summer conditions. The WSSC data contained five data points, three centered around the Western Branch WWTP and two in the Patuxent River. Since the modeling domain does not include the Patuxent, the model results were plotted against the three data points in the Western Branch.

The upstream boundary condition used in the post-audit represents low flow conditions from August 1995 at water quality station WXT0045. The Charles Branch boundary condition represents summer data observed throughout the basin. The BOD boundary conditions at the upstream boundary and Charles Branch were taken from a report of dry weather in-stream water quality analysis performed by Prince George's County (Cheng). The point source loads represent August 1995 conditions, and were taken from MDE's point source database.

The model results were plotted against the three data points for July, August, and September of 1995, 1996, and 1997. As can be seen in Figure A18 the model did an excellent job of replicating the summer BOD concentrations. Figure A19 shows that the model replicated the summer dissolved oxygen concentrations.

SYSTEM RESPONSE

Scenario Descriptions

The model was applied to several different scenarios under various nutrient and BOD loading conditions and stream flow conditions to project the water quality response of the system. By modeling different loading conditions, the scenarios identified which water quality constituent was principally responsible for the low dissolved oxygen in the river. By modeling several stream flow conditions, the scenarios simulate seasonality.

The first scenario represents the system during summer low flow conditions. A flow of 3 cfs was used, which represents the 7-day consecutive lowest flow expected to occur every 10 years, known as the 7Q10 flow. The flow from Charles Branch was calculated as a portion of the Western Branch flow based on the relative drainage area size of the two watersheds. The nonpoint source loads at the upper boundary reflect average values observed in the Western Branch watershed during August 1995. August 1995 was used because a flow analysis determined it to be a relatively low flow month (10 cfs), and therefore a reasonable estimate of the loads that would be seen during 7Q10 flow. BOD data was not measured in the MDE/DNR data set used to estimate the other boundary conditions. The BOD boundary concentrations were estimated from a statistical analysis performed by Prince George’s County (Cheng) of dry weather samples on the nearby Collington Branch.

The nonpoint source loads from Charles Branch for dissolved oxygen, ammonia, and organic nitrogen were representative of average concentrations over the months July through September, for various water quality stations located in the Western Branch Watershed and nearby Patuxent River/Rt. 214 to Ferry Landing Watershed. Summer low flow values for nitrate, ortho-phosphate, and organic phosphorus were yearly averages, because monthly data was not available. All the data for Charles Branch was collected over the years 1966 to 1979. BOD values were estimated in the same way as was conducted for Western Branch.

The point source loads were computed under the assumption that the Western Branch WWTP and Croom Manor WWTP would be discharging at their current maximum design capacities (30 mgd and 0.0042 mgd, respectively), and maximum concentrations, according to their National Pollutant Discharge Elimination System (NPDES) permits. Because this scenario represents summer low flow conditions, expected summer concentrations were used at both WWTPs. During 7Q10 conditions, no rainfall is expected to occur, therefore no loads were included from the composting facility.

Sensitivity analyses was performed on the first scenario to determine the effects of the dissolved oxygen concentration in the Patuxent River on the dissolved oxygen concentrations in the Western Branch. To do this the dissolved oxygen boundary condition at the confluence with the Patuxent was varied from 5 mg/l to 8 mg/l.

The second scenario represents the system during winter conditions. Low dissolved oxygen concentrations were not expected to occur in the winter. However, to rule out winter as a critical period, the worst possible conditions that could occur in the winter were examined in this scenario. Analysis of the flow data at the USGS station in Upper Marlboro showed that the 1994-1995 hydrologic year was a relatively low flow year. To calculate worst case conditions in the winter, flow from October 16, 1994 to March 31, 1995 was averaged and used in this scenario (76 cfs). Again, the flow from Charles Branch was estimated as a portion of the flow in Western Branch based on relative drainage area sizes. The nonpoint source loads reflect values observed at water quality monitoring stations during the period October through March. The BOD values were again estimated using the Prince George's County analysis (Cheng), however, wet weather analysis was used. The point source loads were computed under the same assumption as scenario one; however, expected winter flows and concentrations were used. At Prince George's County Yardwaste Composting Facility, the load was calculated by multiplying the highest expected runoff volume by the highest BOD value measured between 3/94 to 5/98.

The next three scenarios constitute sensitivity analyses to determine what substances to control to ensure the dissolved oxygen standard is achieved. The third scenario was developed to estimate the effects of reduced nitrogen on the summer critical conditions. The nonpoint source loads were the same as for scenario one. The point source loads were similar to scenario one; however, the amount of nitrogen discharged from the Western Branch WWTP was reduced by 75% to see how this change would effect the dissolved oxygen levels.

The fourth scenario was developed to estimate the effects of reduced phosphorus on the summer critical conditions. The nonpoint source loads were the same as for scenario one. The point source loads were similar to scenario one; however, the amount of phosphorus discharged from the Western Branch WWTP was reduced by 75% to see how this change would effect the dissolved oxygen levels.

The fifth scenario was developed to estimate the effects of reduced BOD on the summer critical conditions. The nonpoint source loads were the same as for scenario one. The point source loads were similar to scenario one; however, the amount of BOD discharged from the Western Branch WWTP was reduced by 75% to see how this change would effect the dissolved oxygen levels.
The next two model scenarios also included a correction for dissolved oxygen. The WBEM is capable of calculating the daily average dissolved oxygen concentrations in the stream as well as the minimum concentration. The daily average is not necessarily a good overall measure 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 within algae, which utilizes 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. At the same time, however, the algae require oxygen for respiration.

Minimum values of dissolved oxygen usually occur in the early morning predawn 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 to 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 events. The diurnal dissolved oxygen variation due to photosynthesis and respiration can be estimated by the WBEM and subtracted from the average to produce the minimum dissolved oxygen concentration. The dissolved oxygen concentrations plotted for scenarios six and seven are the minimum concentrations, as calculated by the model.

The sixth scenario determines the effects of increased dissolved oxygen effluent concentrations at the Western Branch WWTP. The nonpoint source loads were the same as for scenario one. The point source loads were the same as scenario one; however, the dissolved oxygen concentration in the effluent discharged from the Western Branch WWTP was increased to 7 mg/l.

The seventh scenario shows the effects of the proposed final solution, including a margin of safety and a future allocation. The nonpoint source loads were increased from scenario one to include a future allocation for upstream sources, and a 5% margin of safety. The point source loads were similar to scenario 6; however, an additional BOD margin of safety was added at the Western Branch WWTP and Croom Manor WWTP. The margin of safety was calculated as 10% of the difference between the weekly and monthly limits at the two WWTPs. The nonpoint source concentrations and flows for scenarios 1 through 5 can be seen in Table A6. Table A7 shows the point source effluent concentrations and flows for these same scenarios. The point and nonpoint source loads and flows for scenarios 6 and 7 can be seen in the technical memorandum entitled *Significant Biochemical Oxygen Demand Point and Nonpoint Sources in the Western Branch Watershed, Prince George's County, Maryland*.

Several more sets of model scenarios were completed after the seventh. These runs show the effects of higher flows and loads in the system. For each of these runs, the flows were increased to ensure that the proposed final solution maintained water quality standards in the river at flows greater than 7Q10. The concentrations at the upper boundary and the Charles Branch boundary remained the same, however the flows were increased. Increasing the flows also increases the loads, which were the main concern in these runs. Nothing was changed at the WWTPs.

Model Results

The first scenario represents the critical conditions of the system during summer low stream flow. Figures A20 through A24 show the model results from scenarios one and two. As seen in Figure A22, the dissolved oxygen level goes below the water quality standard of 5 mg/l. The results of the second scenario, seen in Figure A21, show the system to be unimpaired by low dissolved oxygen concentrations during winter conditions.

The sensitivity analysis on the first scenario showed that even if the dissolved oxygen concentration in the Patuxent River was well above the standard (8 mg/l), the minimum daily average dissolved oxygen concentration in the Western Branch was 4.15 mg/l. The results of this scenario (Patuxent DO Sensitivity Run) and scenario one can be seen in Figure A25.

The results of scenario three as shown, in Figure A28, indicate that, even with the point source nitrogen loads decreased by 75%, the water quality standard for dissolved oxygen is barely met at all locations along the portion of the Western Branch that was modeled. The system is not highly sensitive to changes in nitrogen. The results of scenario four show that a reduction in point source phosphorus has no effect on the dissolved oxygen concentration in the river. The system is not sensitive to changes in phosphorus. The fifth scenario shows that with a reduction in BOD, the water quality standard for dissolved oxygen is comfortably met at all locations within the Western Branch modeling domain. These results indicate that BOD is the principal controlling factor of dissolved oxygen in the Western Branch. The results from model scenarios three, four, and five can be seen in Figures A26 to A30.

The results of scenario six, as seen in Figure A33, show that when the dissolved oxygen level in the effluent is increased to 7 mg/l there are no water quality violations of the dissolved oxygen standard along the entire length of the river. The results from scenario seven show that when a BOD margin of safety is added to the system, the dissolved oxygen standard is still met along the entire length of the river. The results from model scenarios six and seven can be seen in Figures A31 through A35.

Figure A36 shows the results of the final model runs with varying flows. The low dissolved oxygen in the system occurred at model segment seven, and is shown as the y-axis on the graph. As can bee seen, the dissolved oxygen standards are maintained at flows higher than the 7Q10 flow.

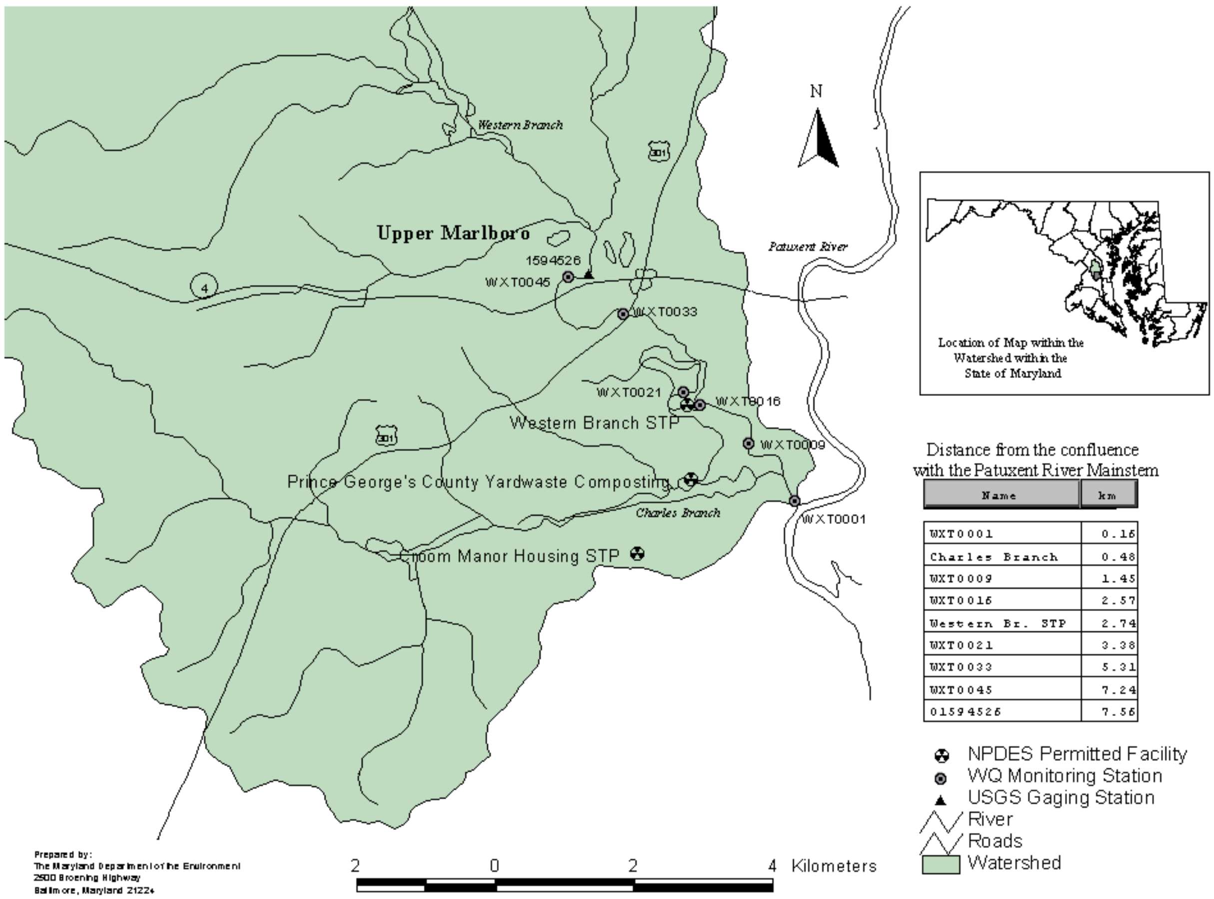


Figure A1: Location of Water Quality Monitoring Stations and Other Points of Interest

Table A1: Field and Laboratory Protocols Used to Collect Water Quality Samples

Parameter (units)	Dectection Limits	Method Reference
IN SITU:		
Flow	0.01 cfs	Meter (Marsh-McBirney or Pygmy Sampler)
Temperature	-5 deg. C	Linear thermistor network; Hydrolab System 8000 Water Quality Instrumentation Manual (1978) (HSWQIM)
Dissolved Oxygen (ppm)	0 ppm	Au/Ag polargraphic cell (Clark); HSWQIM
Conductivity (mmhos/cm)	0 mmhos/cm	Temperature-compensated, four electrode cell; HSWQIM
pH	1 pH	Glass electrode: Ag/AgCl reference electrode pair; HSWQIM
Secchi Depth	0.1 m	20.3 cm disk
GRAB SAMPLES:		
Total Alkalinity	0.01 mg/l	Filtration ** EPA No. 310
Total Organic Carbon (mg/l as C)	1 mg/l	Adapted from **EPA method No. 425.2
Turbidity	0.1 FTU	Light scatter **EPA No. 1979
Total Suspended Solids	1mg/l	Standard Methods for the Examination of Water and Wastewater (15th ed.) sect. 209D, p. 94
Total Kjeldahl Nitrogen unfiltered (mg/l as N)	0.2 mg/l	Technicon Industrial Method # 376-75W/b; #329-74W/B
Ammonia (mg/l as N)		Technicon Industrial Method # 154-71W/B
Nitrate (mg/l as N)		Technicon Industrial Method # 154-71W/B2
Nitrite (mg/l as N)		Technicon Industrial Method # 102-70W/C
Total Phosphorus		Technicon Industrial Method # 376-75W/B; #329-74/B
Ortho-phosphate (mg/l as P)		Technicon Industrial Method # 155-71W
Chlorophyll a	1 mg/cu. M	Standard Methods for the Examination of Water and Wastewater (15th ed.) #1002G. Chlorophyll. Pp 950-954.
BOD5	0.01 mg/l	Oxidation ** EPA No. 405

** EPA Chemical Analysis for Water and Wastes (March, 1979). EPA-600/79-020

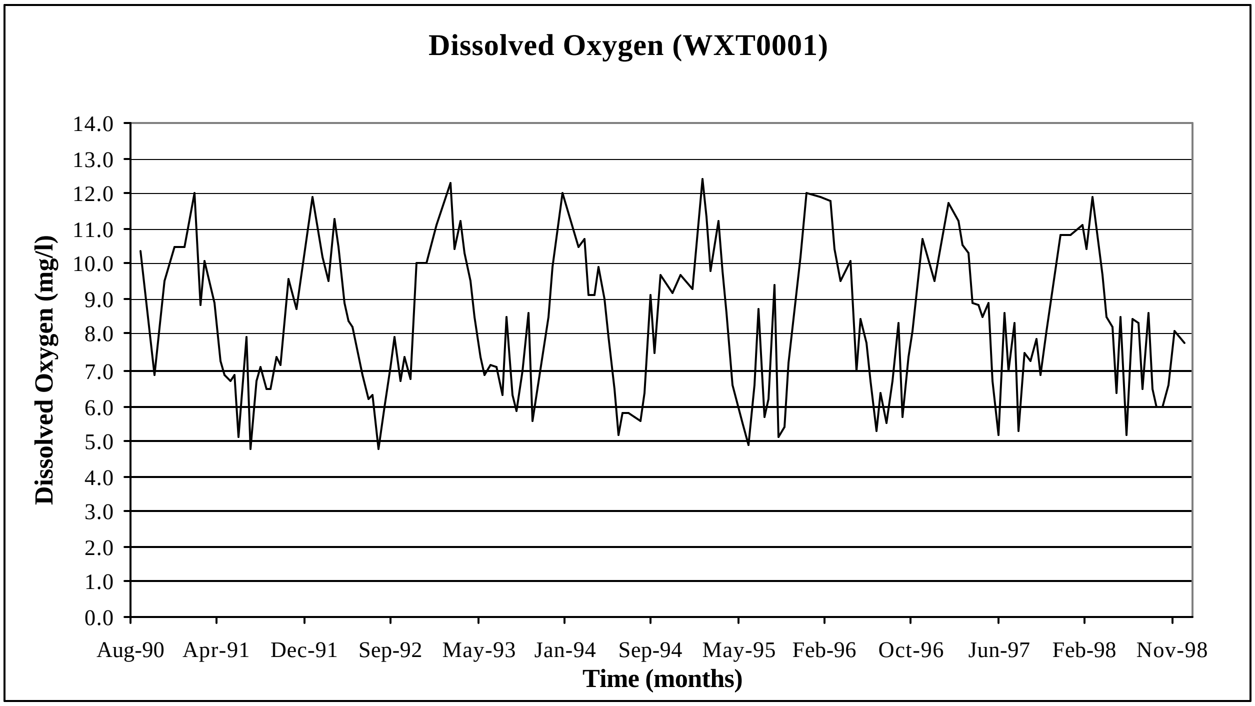


Figure A2: Dissolved Oxygen Concentrations at Water Quality Station WXT0001

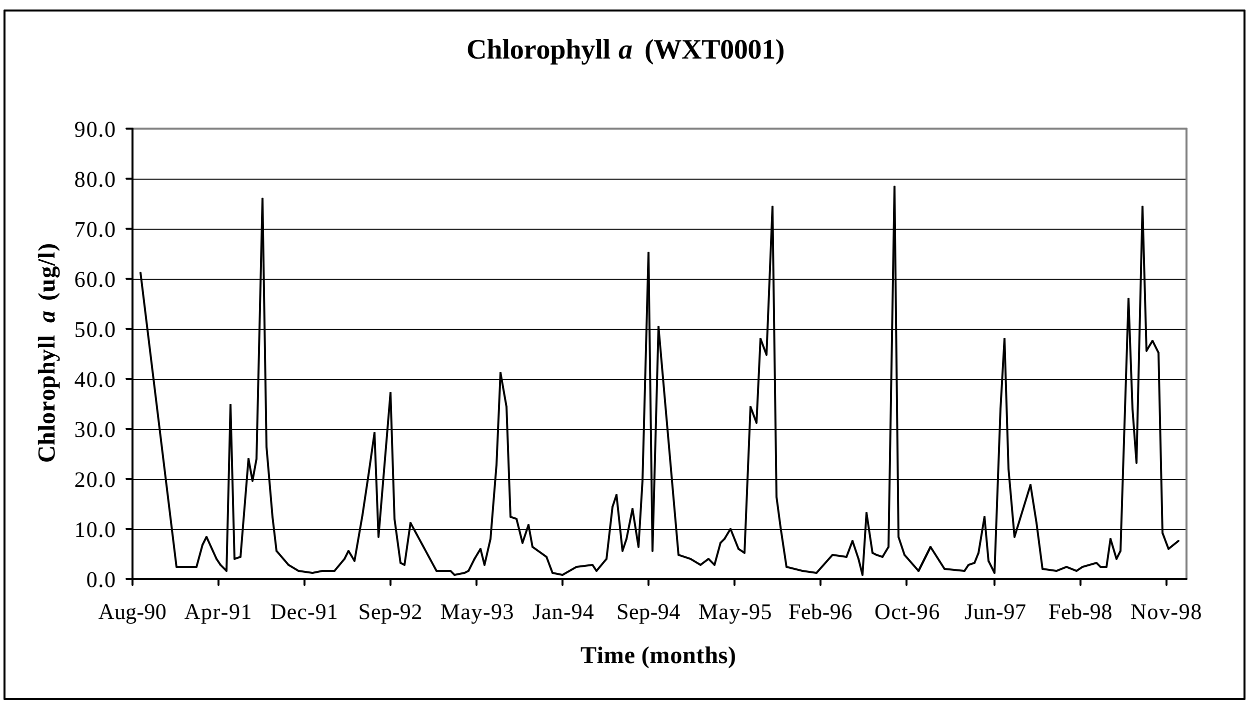


Figure A3: Chlorophyll *a* Concentrations at Water Quality Station WXT0001

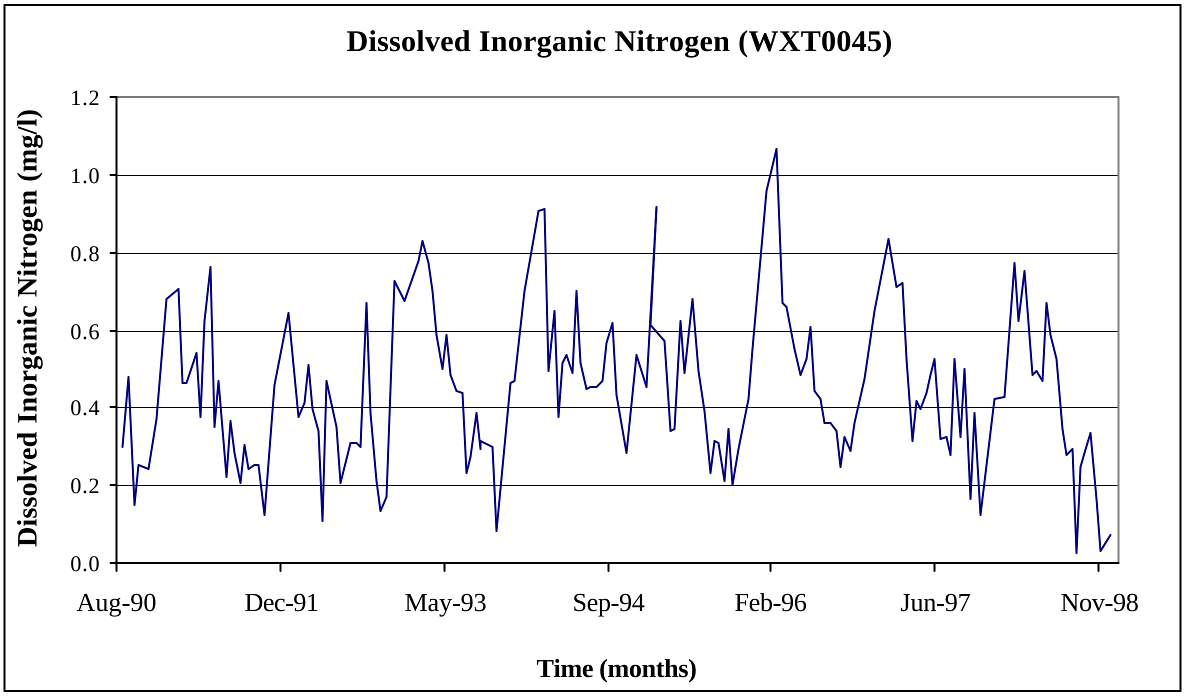


Figure A4: Dissolved Inorganic Nitrogen Concentrations at Water Quality Station WXT0045

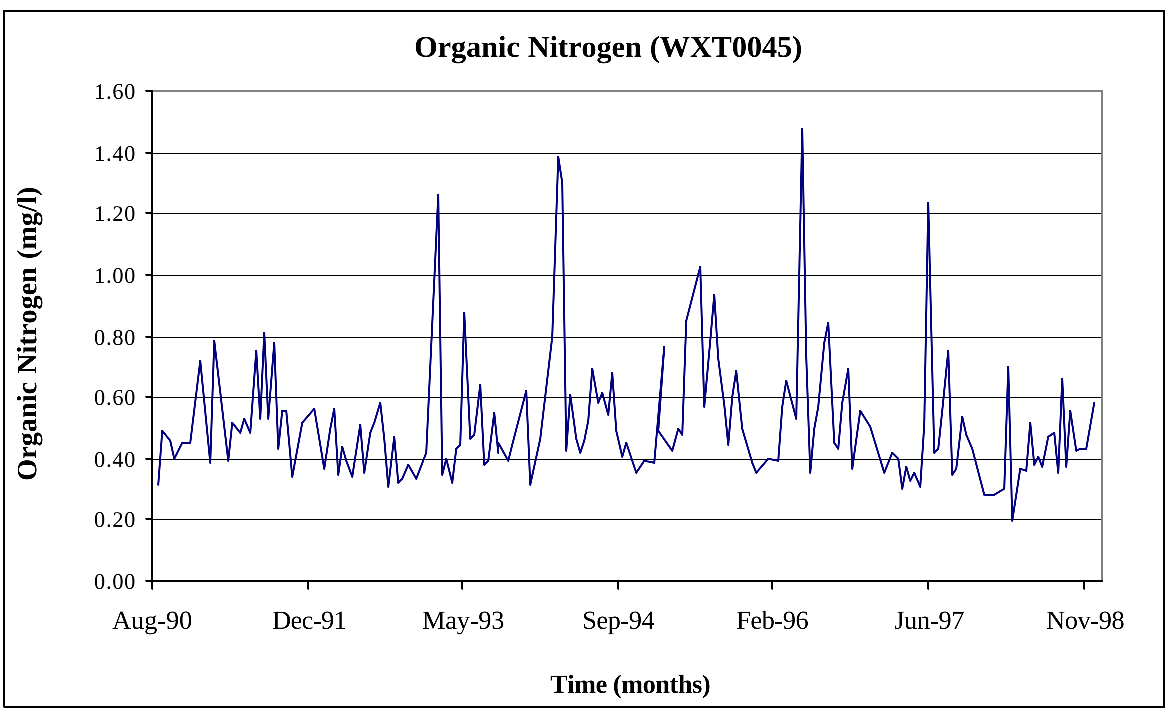


Figure A5: Organic Nitrogen Concentrations at Water Quality Station WXT0045

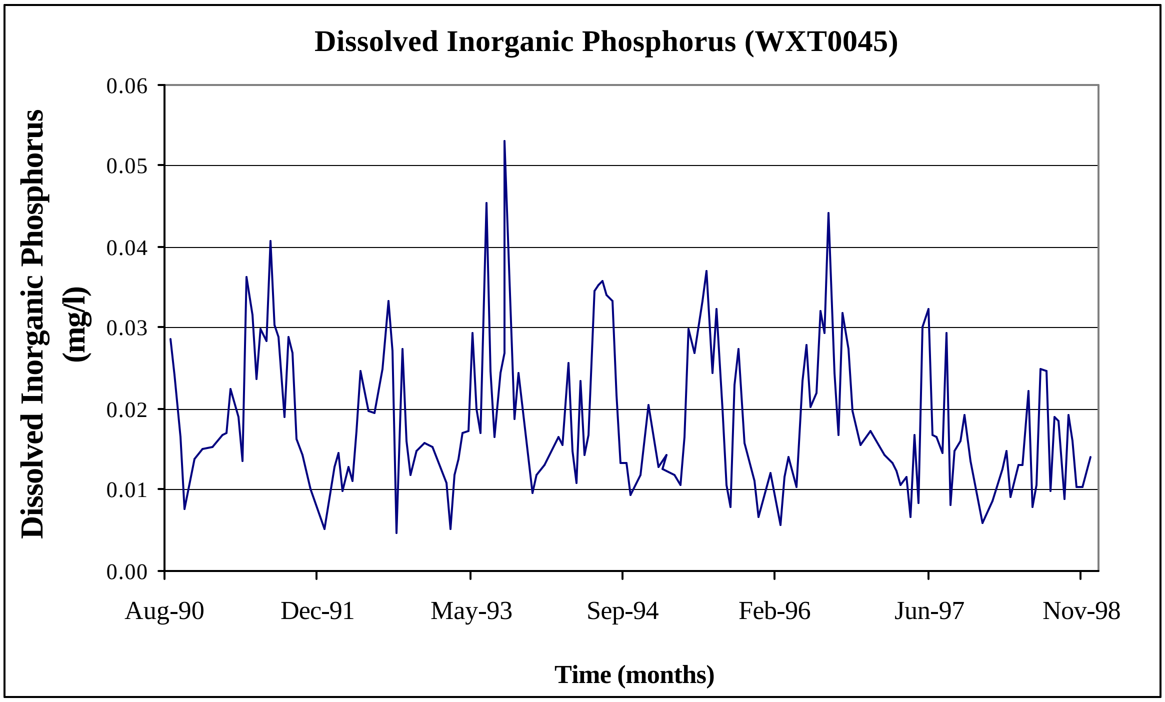


Figure A6: Dissolved Inorganic Phosphorus Concentrations at Water Quality Station WXT0045

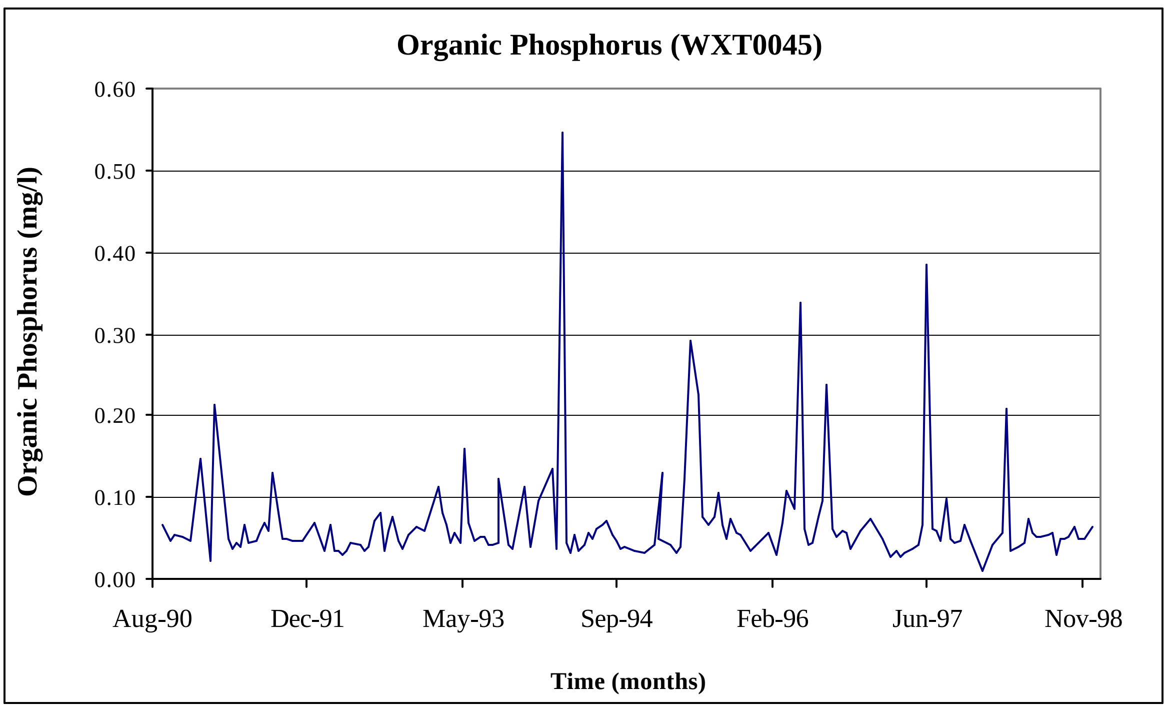


Figure A7: Organic Phosphorus Concentrations at Water Quality Station WXT0045

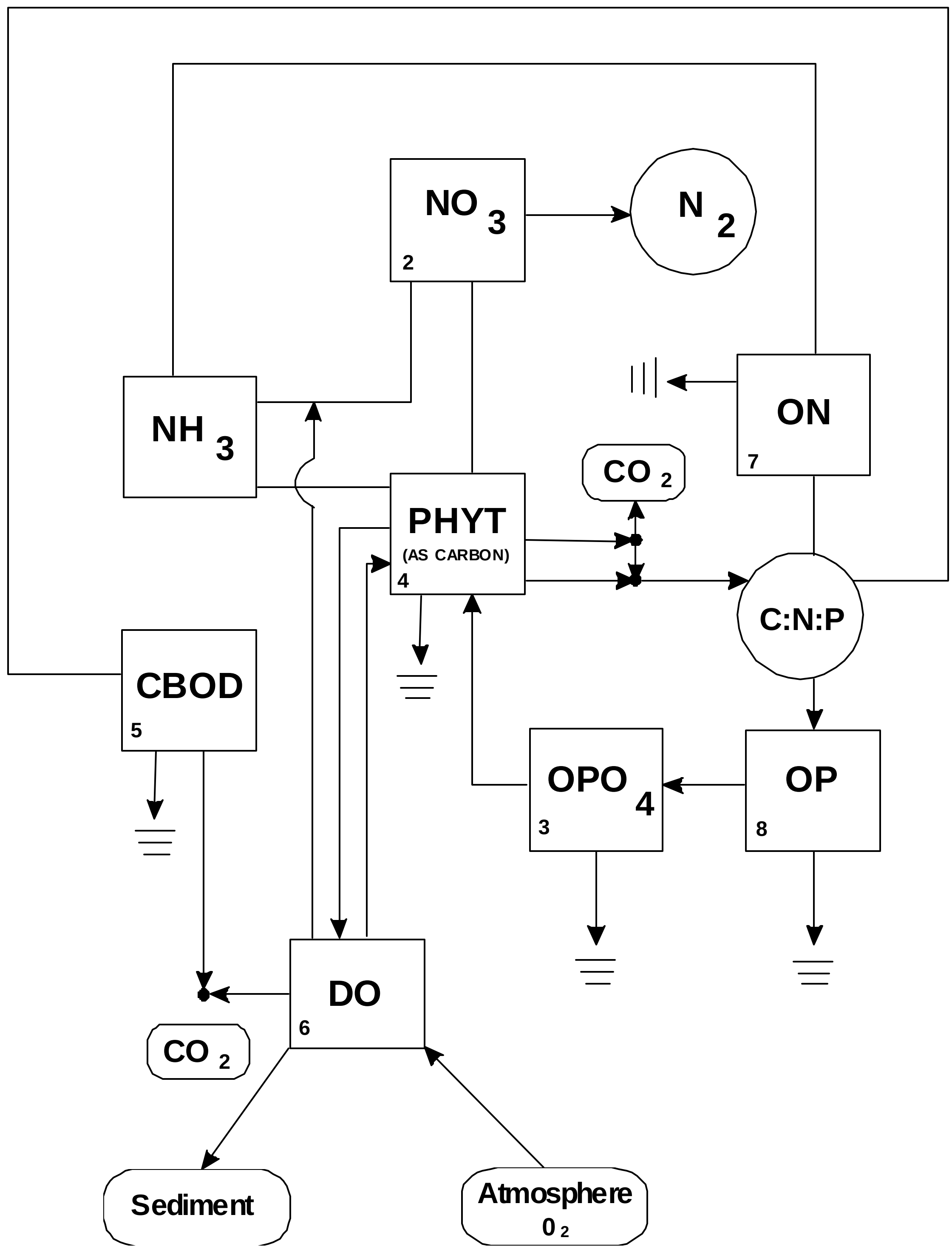


Figure A8: State Variables and Kinetic Interactions in EUTRO5.1

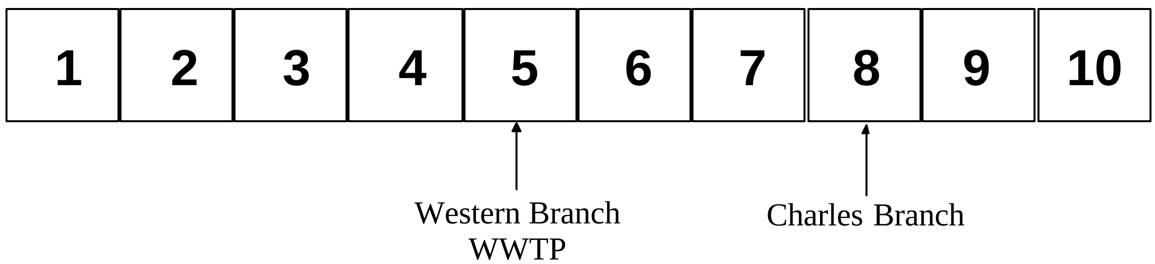


Figure A9: Spatial Domain of the Western Branch Eutrophication Model

Table A2: Volumes, Characteristic Lengths, and Interfacial Areas of the Western Branch Model Segments

Segment No.	Volume m^3	Characteristic Length m	Interfacial Area m^2
1	5,383	750	9
2	8,075	750	13
3	11,107	750	17
4	14,510	713	22
5	18,152	675	32
6	24,736	626	41
7	28,479	578	58
8	38,747	323	77
9	5,224	68	78
10	6,237	100	108

Table A3: Nonpoint Source Flow and Concentrations used in the Calibration of the Model

		Western Branch	Charles Branch
Chl *a*	*ug/l*	5.00	5.00
BOD_5	*mg/l*	1.8	1.8
DO	*mg/l*	12.8	12.2
NH_3	*mg/l*	0.0590	0.745
ON	*mg/l*	0.411	0.362
NO23	*mg/l*	0.391	0.251
PO_4	*mg/l*	0.0610	0.110
OP	*mg/l*	0.0210	0.084
Flow	m^3/s	1.18	0.077
Total Nitrogen	*mg/l*	0.861	1.36
Total Phosphorus	*mg/l*	0.0820	0.194

Table A4: Point Source Flow and Loads used in the Calibration of the Model

		Western Branch WWTP	Croom Manor WWTP
BOD_5	*kg/d*	126	0.086
DO	*kg/d*	586	0.0398
NH_3	*kg/d*	12.7	0.152
ON	*kg/d*	51.0	0.00480
NO23	*kg/d*	1019	0.178
PO_4	*kg/d*	31.9	0.0131
OP	*kg/d*	12.7	0.00170
Flow	m^3/s	0.738	0.000092
Total Nitrogen	*kg/d*	1083	0.335
Total Phosphorus	*kg/d*	44.6	0.0148

Table A5: Kinetic Coefficient Used in the WBEM

Constant	Code	Value
Nitrification rate	K12C	0.08 *day* -1 at 20^o C
temperature coefficient	K12T	1.08
Denitrification rate	K20C	0.0 *day* -1 at 20^o C
temperature coefficient	K20T	1.08
Saturated growth rate of phytoplankton	K1C	1.7 *day* -1 at 20^o C
temperature coefficient	K1T	1.06
Endogenous respiration rate	K1RC	0.125 *day* -1 at 20^o C
temperature coefficient	K1RT	1.045
Nonpredatory phytoplankton death rate	K1D	0.125 *day* -1
Phytophankton Stoichometry		
Oxygen-to-carbon ratio	ORCB	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	0.001 *mg* P / P
Decomp. rate const. for phytoplankton in sediment	KPZDC	0.02 *day* -1 at 20^o C
Fraction of dead phytoplankton recycled to organic		
nitrogen	FON	1.0
phosphorus	FOP	1.0
Light Formulation Switch	LGHTS	1 = Smith
Saturation light intensity for phytoplankton	IS1	350. *Ly/day*
BOD deoxygenation rate	KDC	0.20 *day* -1 at 20^o C
temperature coefficient	KDT	1.05
Reaeration rate constant	k2	0.50 *day* -1 at 20^o C
Mineralization rate of dissolved organic nitrogen	K71C	0.02 *day* -1
temperature coefficient	K71T	1.08
Mineralization rate of dissolved organic phosphorus	K58C	0.20 *day* -1
temperature coefficient	K58T	1.08
Phytoplankton settling velocity		0.229 *m/day*
Inorganics settling velocity		0.186 *m/day*

Figure A10: Results of the Calibration of the Model for BOD

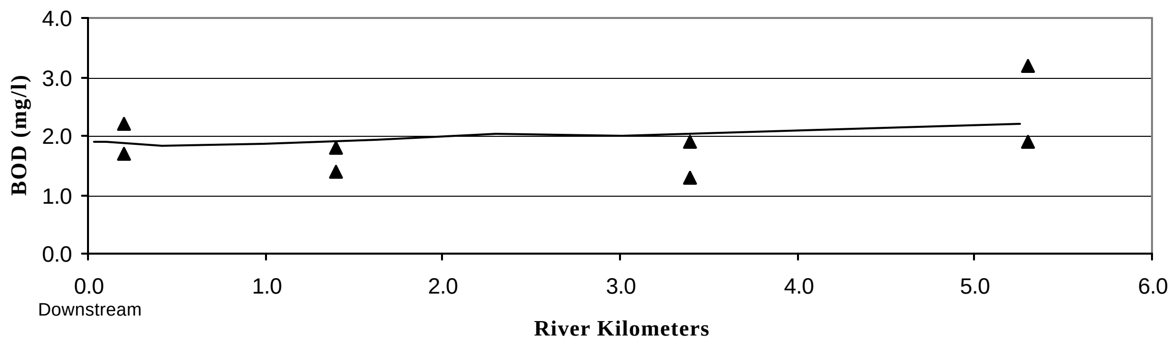


Figure A11: Results of the Calibration of the Model for Dissolved Oxygen

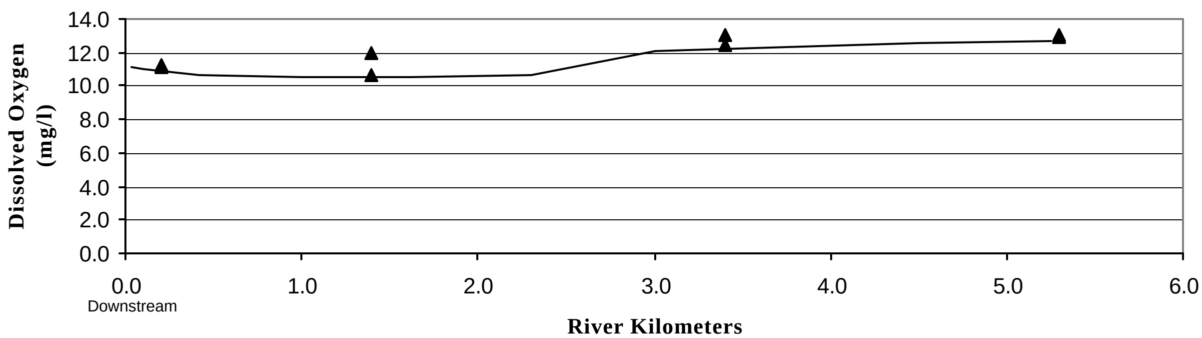


Figure A12: Results of the Calibration of the Model for Chlorophyll *a*

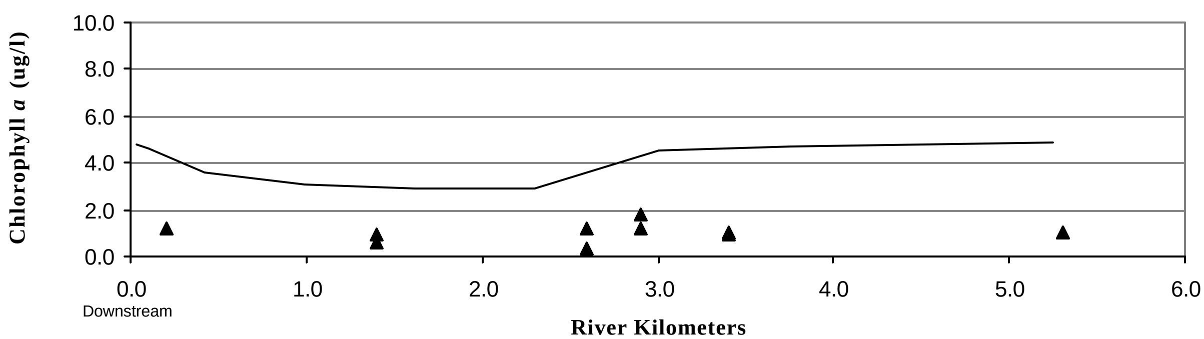
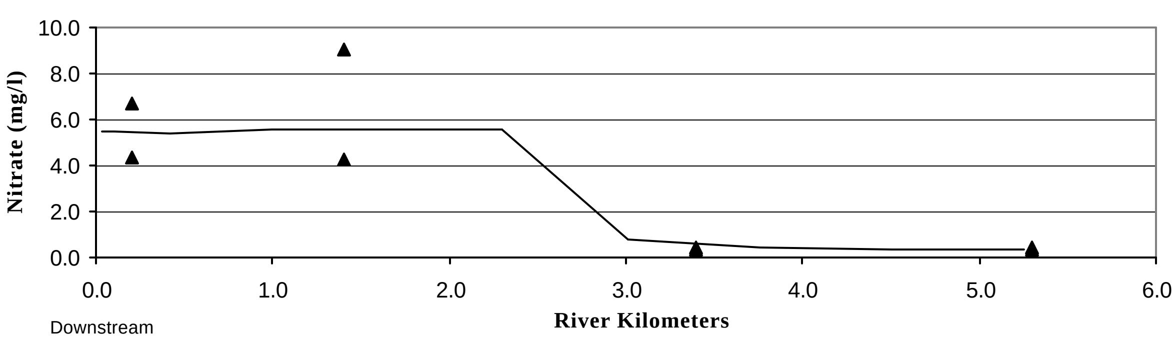


Figure A13: Results of the Calibration of the Model for Nitrate



Model Results Data

Figure A14: Results of the Calibration of the Model for Organic Nitrogen

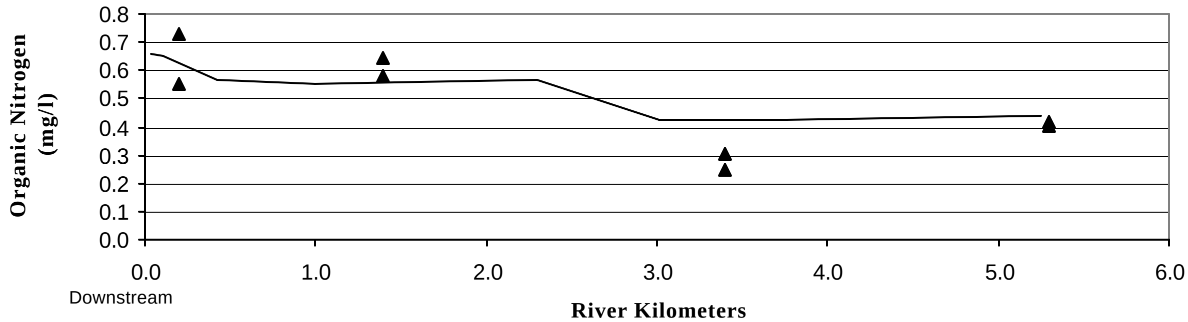


Figure A15: Results of the Calibration of the Model for Ammonia

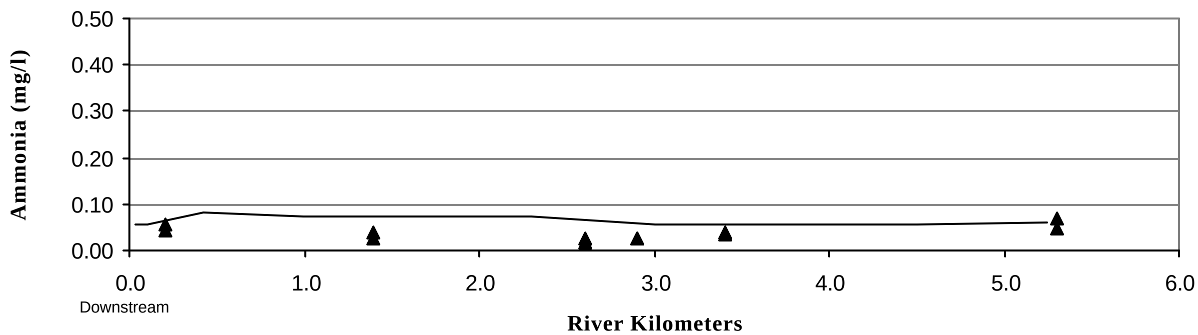


Figure A16: Results of the Calibration of the Model for Organic Phosphorus

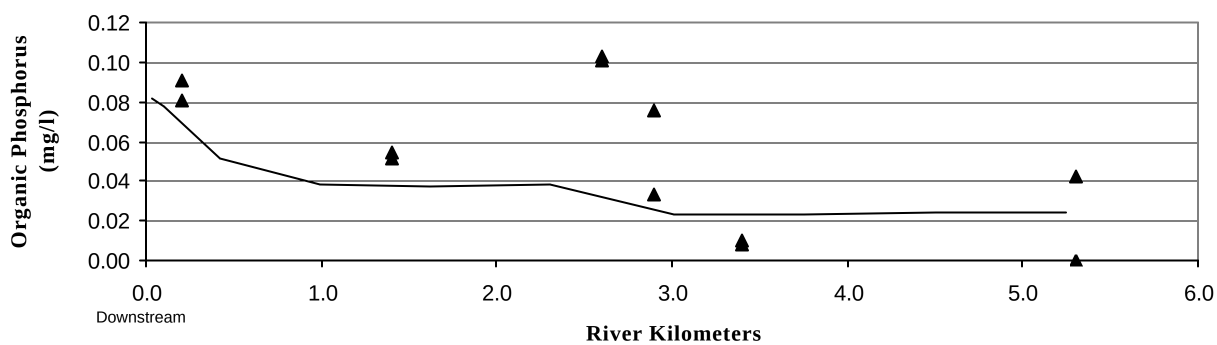


Figure A17: Results of the Calibration of the Model for Ortho-Phosphate

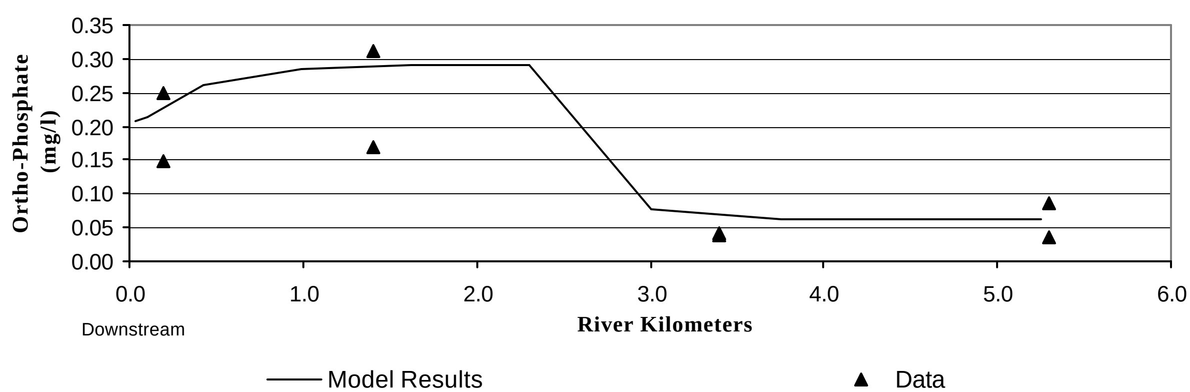


Figure A18: Results of the Post-Audit of the Model for BOD

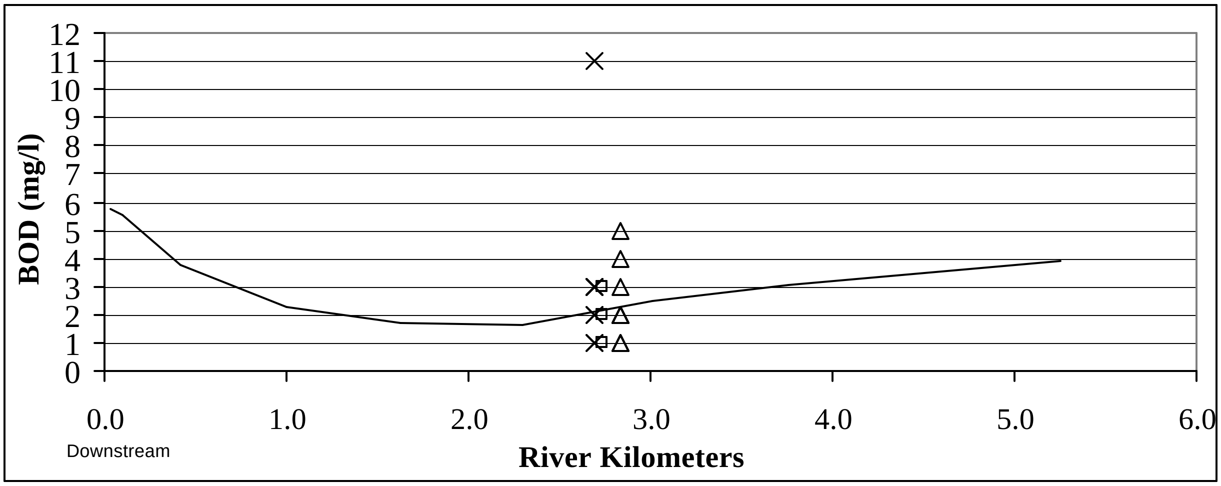


Figure A18: Results of the Post-Audit of the Model for Dissolved Oxygen

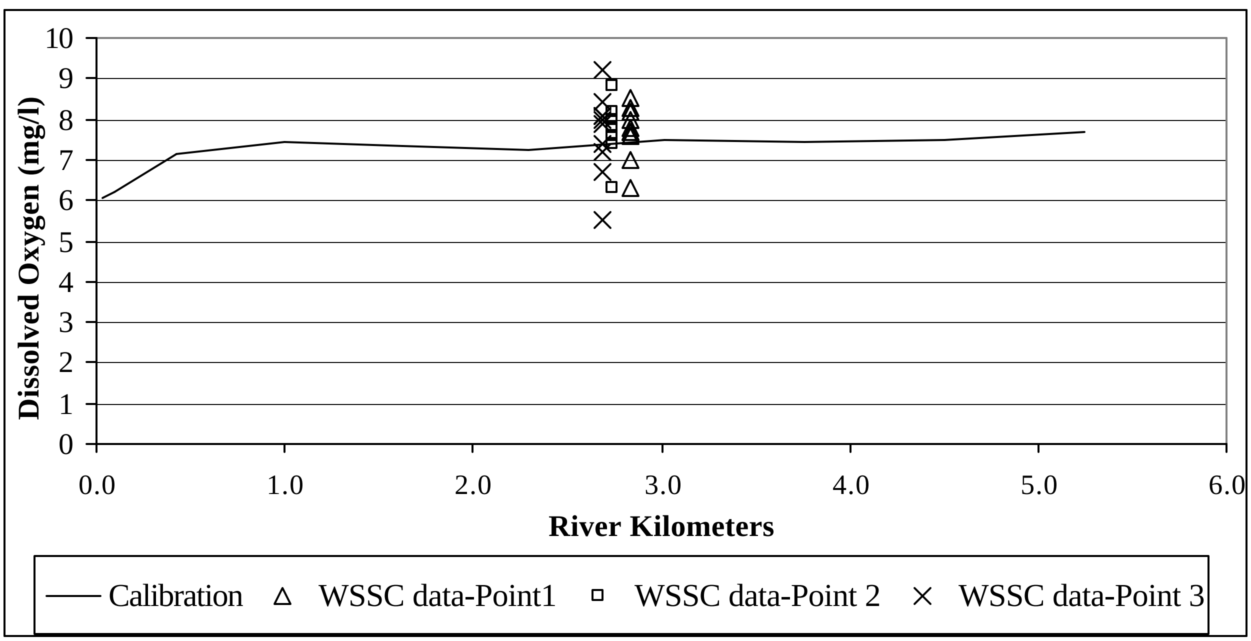


Table A6: Nonpoint Source Loads Used in the Model Scenario Runs

Scenario		1	2	3	4	5
Mainstem Western Branch						
CBOD	*mg/l*	3.33	7.50	3.33	3.33	3.33
Dissolved Oxygen	*mg/l*	7.95	10.76	7.95	7.95	7.95
Total Nitrogen	*mg/l*	0.96	1.00	0.96	0.96	0.96
Total Phosphorus	*mg/l*	0.10	0.07	0.10	0.10	0.10
Flow	m^3/s	0.08	1.39	0.08	0.08	0.08
Charles Branch						
CBOD	*mg/l*	3.33	7.50	3.33	3.33	3.33
Dissolved Oxygen	*mg/l*	8.05	11.40	8.05	8.05	8.05
Total Nitrogen	*mg/l*	0.88	0.82	0.88	0.88	0.88
Total Phosphorus	*mg/l*	0.20	0.20	0.20	0.20	0.20
Flow	m^3/s	0.006	1.387	0.006	0.006	0.006

Table A7: Point Source Loads Used in the Model Scenario Runs

Scenario		1	2	3	4	5
Western Branch WWTP						
Effluent Concentrations						
CBOD	*kg/d*	1895.0	5686.0	1895.0	1895.0	473.0
Dissolved Oxygen	*kg/d*	568.6	568.6	568.6	568.6	568.6
Total Nitrogen	*kg/d*	341.2	1671.8	85.3	341.2	341.2
Total Phosphorus	*kg/d*	113.7	113.7	113.7	28.4	113.7
Flow	m^3/s	1.314	1.314	1.314	1.314	1.314
Charles Branch Point Sources						
Effluent Concentrations						
CBOD	*kg/d*	0.379	5252.0	0.379	0.379	0.379
Dissolved Oxygen	*kg/d*	0.080	0.080	0.080	0.080	0.080
Total Nitrogen	*kg/d*	0.298	123.0	0.298	0.298	0.298
Total Phosphorus	*kg/d*	0.027	12.56	0.027	0.027	0.027
Flow	m^3/s	0.00018	0.2232	0.00018	0.00018	0.00018

Figure A20: Chlorophyll *a* Concentrations for Model Scenarios 1 and 2

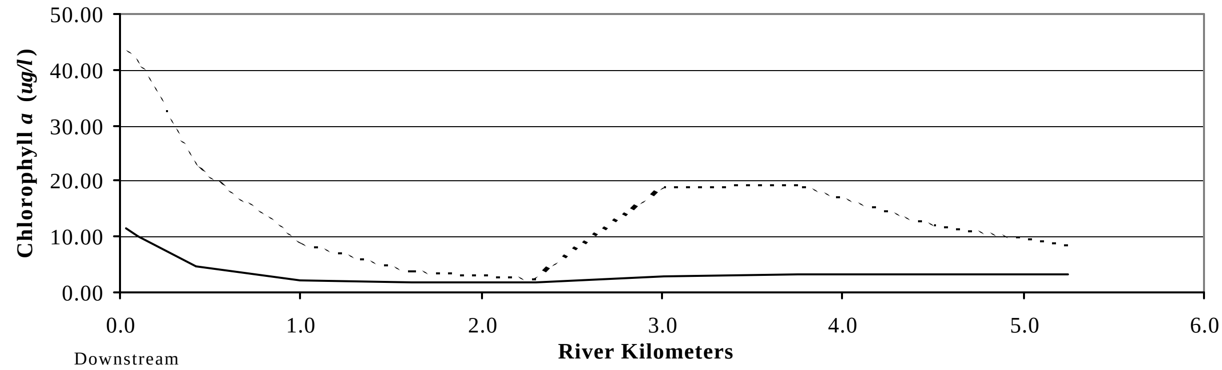


Figure A21: BOD Concentrations for Model Scenarios 1 and 2

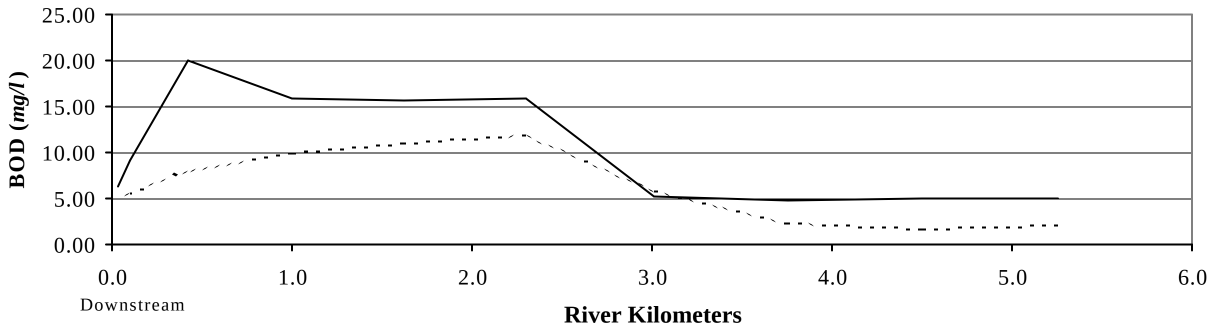


Figure A22: Dissolved Oxygen Concentrations for Model Scenarios 1 and 2

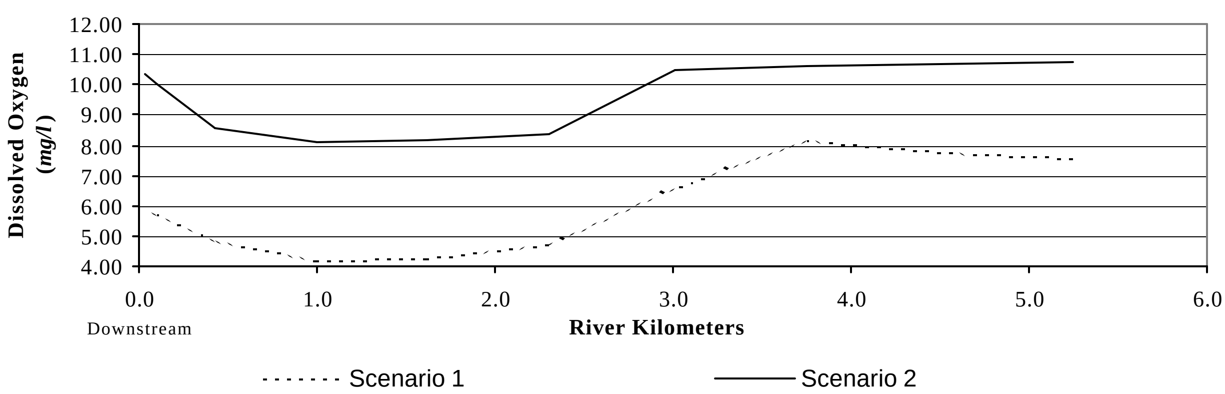


Figure A23: Total Phosphorus Concentrations for Model Scenarios 1 and 2

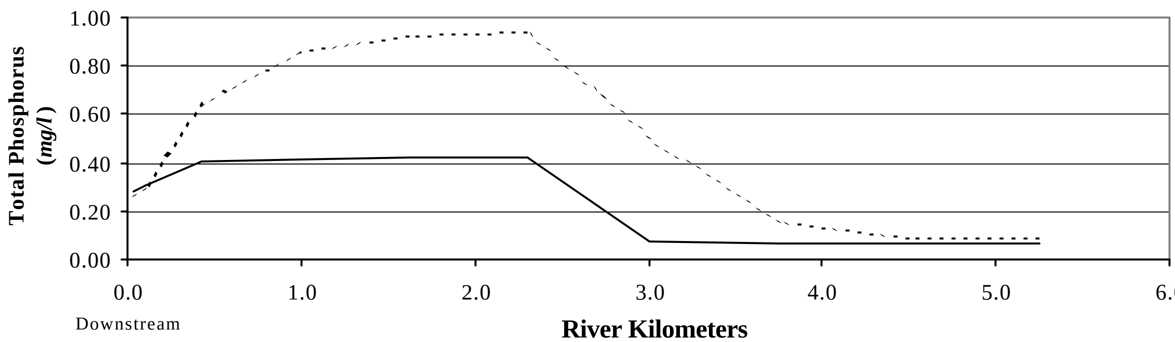


Figure A24: Total Nitrogen Concentrations for Model Scenarios 1 and 2

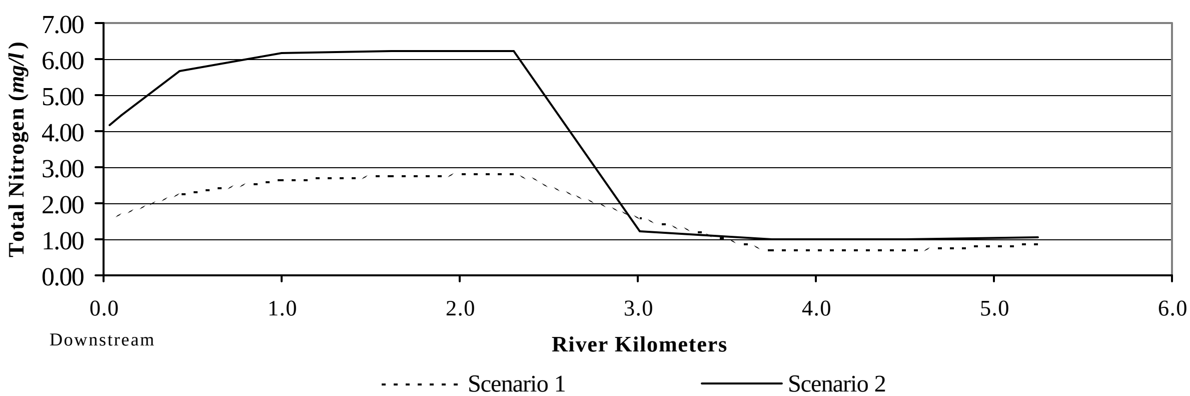


Figure A25: Dissolved Oxygen Concentration of Patuxent River Sensitivity Run and Scenario 1

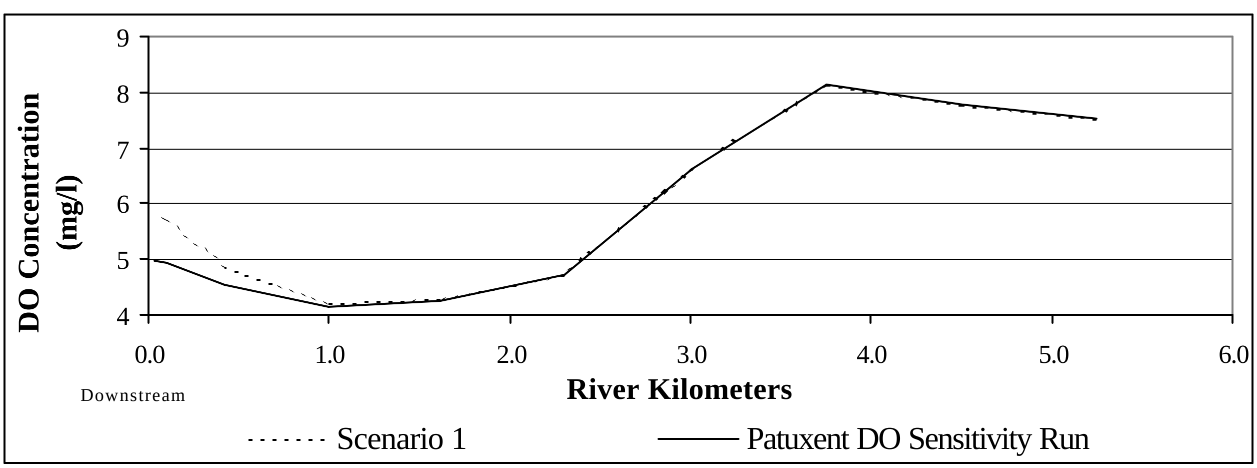


Figure A26: Chlorophyll *a* Concentrations for Model Scenarios 3, 4, and 5

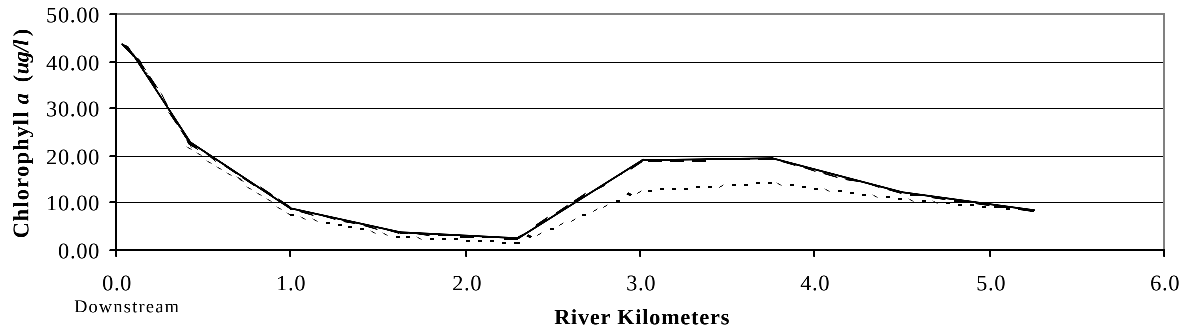


Figure A27: BOD Concentrations for Model Scenarios 3, 4, and 5

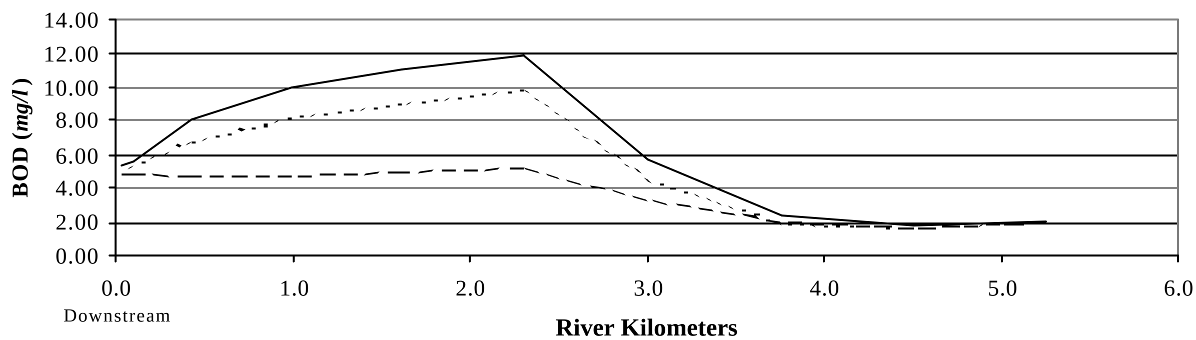


Figure A28: Dissolved Oxygen Concentrations for Model Scenarios 3, 4, and 5

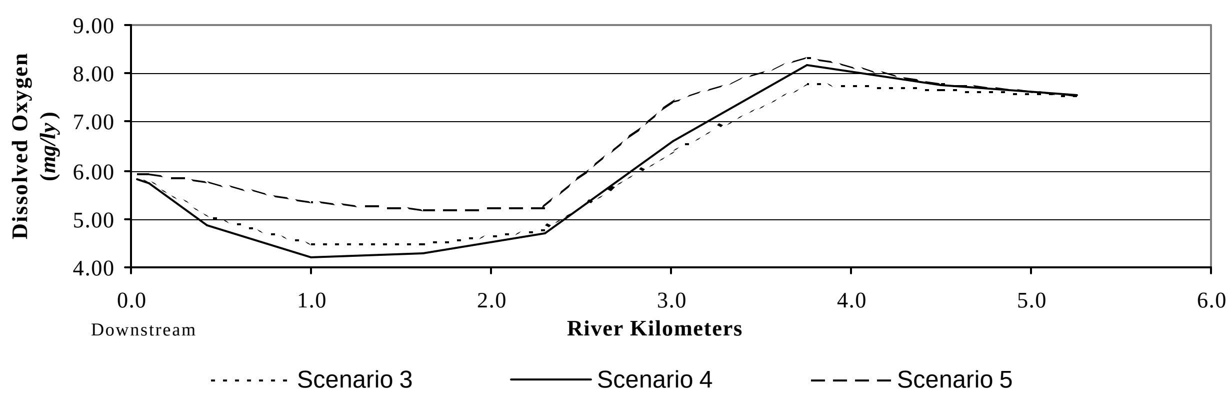


Figure A29: Total Phosphorus Concentrations for Model Scenarios 3, 4, and 5

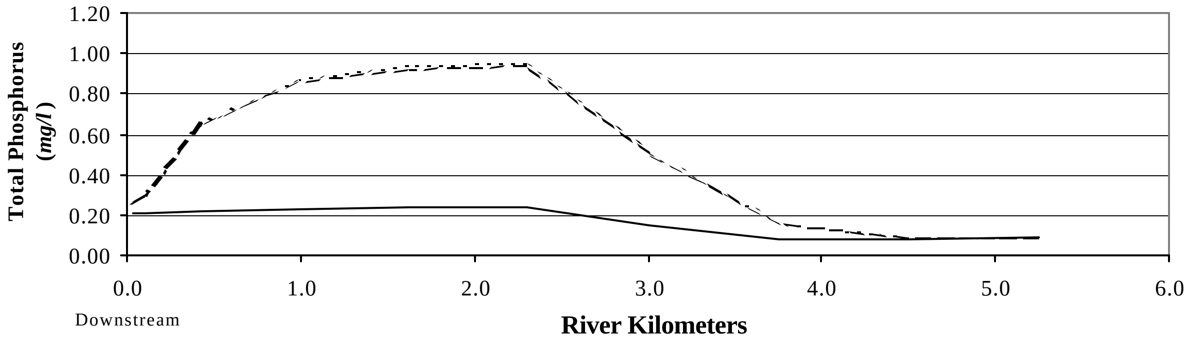


Figure A30: Total Nitrogen Concentrations for Model Scenarios 3, 4, and 5

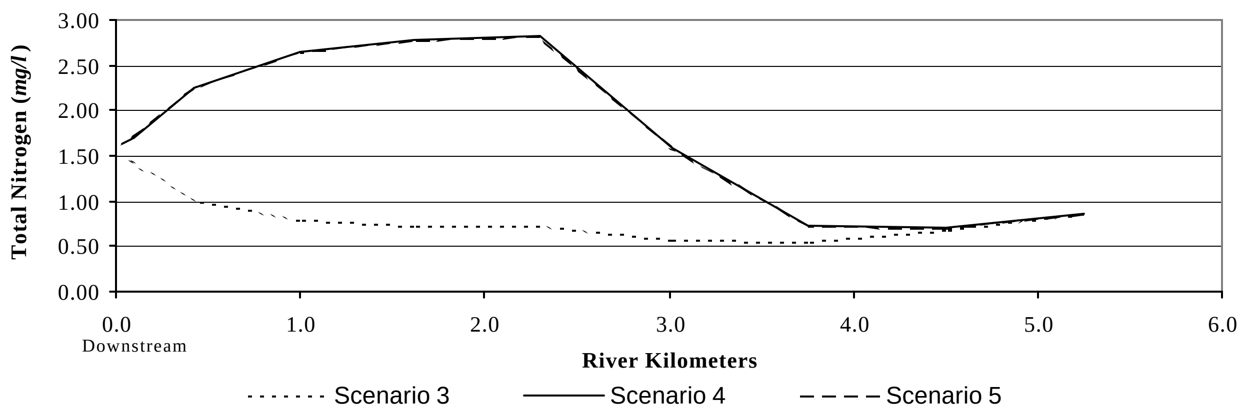


Figure A31: Chlorophyll *a* Concentrations for Model Scenarios 6 and 7

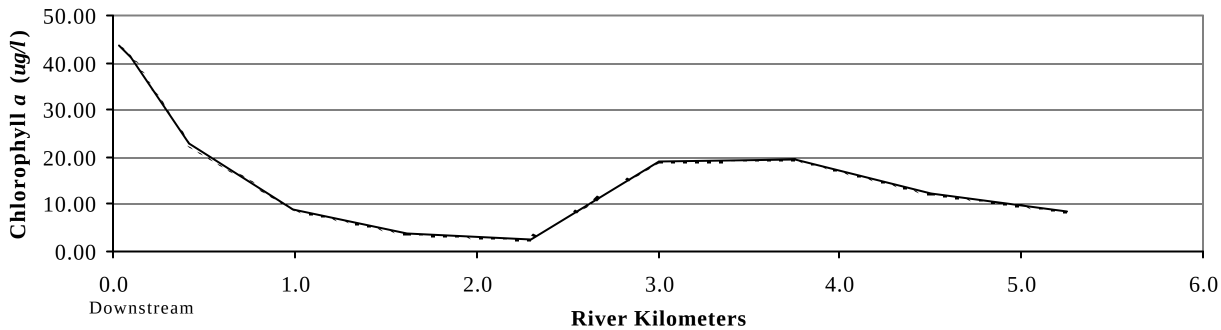


Figure A32: BOD Concentrations for Model Scenarios 6 and 7

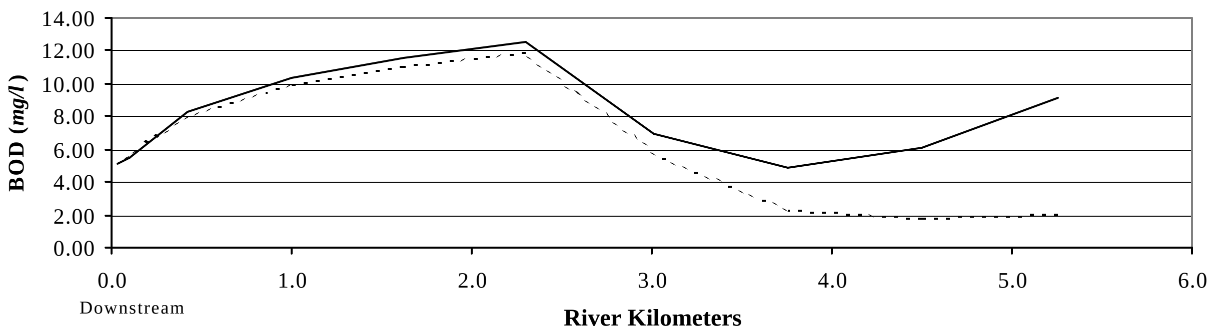


Figure A33: Dissolved Oxygen Concentrations for Model Scenarios 6 and 7

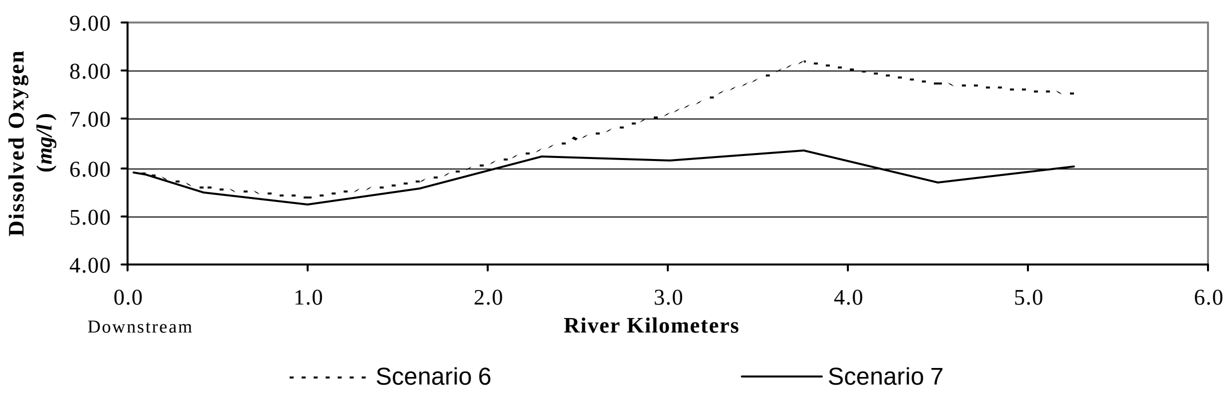


Figure A34: Total Phosphorus Concentrations for Model Scenarios 6 and 7

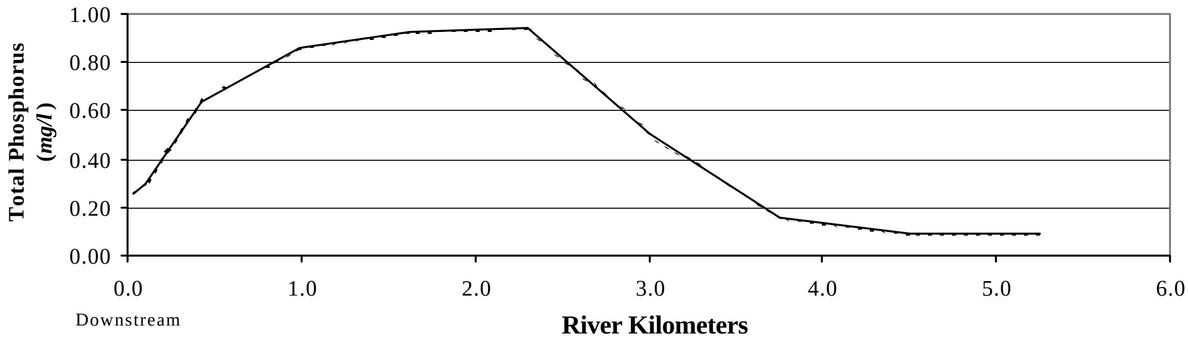


Figure A35: Total Nitrogen Concentrations for Model Scenarios 6 and 7

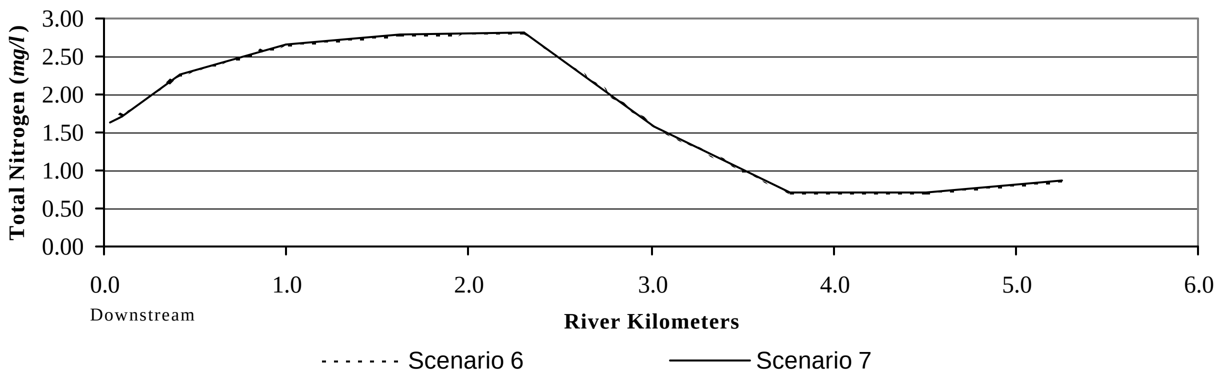
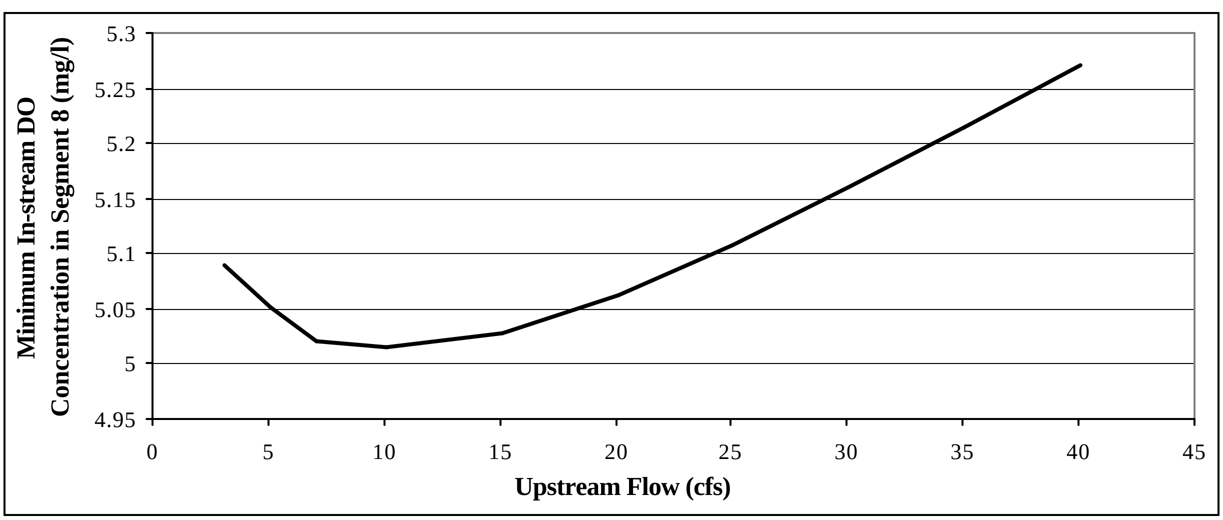


Figure A36: Low Dissolved Oxygen vs. Flow at the Upper Boundary of the Western Branch



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