Appendix A

STUDY AREA

The Port Tobacco River, a tributary of the Potomac River, is located in Charles County Maryland (Figure A1). The River is approximately 13.6 kilometers in length. The watershed of the Port Tobacco has an area of approximately 28,000 acres or 114 square kilometers. The predominant land use in the watershed is forest (17,341 acres or 62%), with mixed agricultural (5,122 acres or 19%) and urban (5,191 acres or 19%). The upper free-flowing portion of Port Tobacco traverses through forest and agricultural lands. The lower, tidal portion enters the Potomac River near Windmill Point in the oligohaline salinity zone. Much of the shoreline of the Port Tobacco River's tidal portion is classified as coastal shallow fresh marsh. Depths of the river range from about 1/2 meter in the headwaters to greater than 11 meters in the tidal zone prior to the river's confluence with the Potomac River (PPSP, DNR).

The tidal portion of Port Tobacco is a slow flowing system located in the Coastal Plain Province. 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 throughout the tidal portion of the river are minimal. Tidal currents in the lower river are extremely weak and variable. 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.

In the Port Tobacco watershed, the estimated total nitrogen load is 99,387 kg/yr, and the total phosphorus load is 6,755 kg/yr, for the year 1996 (US EPA, 1991; MDE 1998). The existing nonpoint source loads were determined using a land use loading coefficient approach. The Port Tobacco Basin was digitized and overlaid onto a land use map using ARC/INFO GIS. The land use map was based on 1994 Maryland Office of Planning data. Next, the total nonpoint source load was calculated summing all of the individual land use areas multiplied by the corresponding land use loading coefficients. The loading rates were based on the results of the Chesapeake Bay Model (U.S. EPA, 1991), which was a continuous simulation model. The Chesapeake Bay Program nutrient loading rates account for atmospheric deposition[1], loads from septic tanks, and loads coming from urban development, agriculture, and forest land. The total nitrogen load coming from nonpoint sources is 86,576 kg/yr, and the total nonpoint source phosphorus load is 5,682 kg/yr.

The point source loads came from the discharge monitoring reports stored MDE's point source database. The year 1996 was used because this is the most recent year for which point source data is presently available. For both nutrients, nonpoint sources are the single greatest load, with

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[1] Atmospheric deposition directly to the water's surface was not taken into account. The surface area of the water in the Port Tobacco Basin only accounts for 6% of the total surface area of the watershed. And, the majority of the water surface, the estuary, is located downstream from the impairment. Thus, the contribution from atmospheric deposition directly to the water's surface was considered insignificant.

agriculture being the dominant source for both nitrogen (42% of the total load and 48% of the nonpoint source) and phosphorus (49% of the total load and 58% of the nonpoint source load). The La Plata Sewage Treatment Plant (STP), with an annual average flow of 0.0395 meters cubed per second (m^3/s) in 1996, is the only major point source (defined under the applicable law as providing discharges with a flow greater than 0.5 mgd) in the watershed. Additionally, there are three other point sources of nutrients in the watershed with a combined flow of 0.0023 m^3/s. The combined total point source contribution in 1996 for nitrogen is 13% and 16% for phosphorus.

WATER QUALITY CHARACTERIZATION

The water quality of four physical parameters, chlorophyll *a*, inorganic phosphorus, nitrate, and dissolved oxygen, were examined to determine the extent of the impairment in Port Tobacco. Four water quality surveys were conducted in the Port Tobacco watershed in August of 1984. Figure A2 identifies the locations of the water chemistry sampled during each survey. The physical and chemical samples were collected by MDE's Field Operations Program staff. 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 0.31 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. The August 1984 data was used to calibrate the model employed in determining the TMDL.

Figure A3 presents an average longitudinal profile of chlorophyll *a* data sampled during field surveys. The sampling region covers the entire tidal portion of the Port Tobacco from its confluence with the Potomac mainstem (Station XDB6884), and includes free flowing stations in an unnamed tributary leading up to and above the La Plata STP. As the data indicates, ambient chlorophyll *a* concentrations for the first four stations are generally about 12 µg/l. However, the levels are much greater at and above Station XDB9786, where mean values are in the range of about 30 µg/l, and maximum nuisance bloom levels are sometimes observed in the range of 70 µg/l in the reach between Station PTC004 and Station PTC0006.

Figure A4 presents a longitudinal profile of inorganic phosphorus as indicated by PO4 levels. In the tidal portion of the Port Tobacco River (below Station PTC0004), PO4 levels are generally less than 0.2 mg/l. However, the concentration of PO4 increases rapidly in the free flowing unnamed tributary, with peak values in the immediate vicinity of the STP outfall exceeding 2.5 mg/l at Station UWV0003. Ambient levels return to approximately 0.1 - 0.2 mg/l above the La Plata facility.

The Nitrate (NO3) levels along the longitudinal gradient are depicted in Figure A5. They are similar to that of PO4, with concentrations in the tidal portion measured at or near the level of detection (0.02 mg/l), but rapidly increasing downstream of the La Plata STP to a maximum concentration of greater than 11.0 mg/l.

Dissolved oxygen concentrations along the longitudinal profile are depicted in Figure A6. Values rarely fall below 8 mg/l, and are typically very close to saturation levels at the measured temperature and salinity ranges.

MODELING FRAMEWORK

The computational framework chosen for the TMDL of Port Tobacco was WASP5. 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, WASP5 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. WASP5 has been used in a wide range of applications by regulatory agencies, consulting firms, and others.

WASP5 is supported and distributed by U.S. EPA's Center for Exposure Assessment Modeling (CEAM) in Athens, GA (Ambrose *et al.*, 1988). EUTRO5 is the component of WASP5 that is applicable of modeling eutrophication, incorporating eight water quality constituents in the water column (Figure A7) and sediment bed. EUTRO5 is used to develop the water quality model of the Port Tobacco system.

INPUT REQUIREMENTS [2]

Model Segmentation and Geometry

The spatial domain of the Port Tobacco Eutrophication Model (PTEM) extends from the confluence of the Port Tobacco River and the Potomac River for about 13.6 kilometers along the mainstem of the Port Tobacco River. Following a review of the bathymetry for the Port Tobacco River, the model was divided into 41 segments. Figure A8 shows the model segmentation and the location of the STPs. Table A2 lists the volumes, characteristic lengths and interfacial areas of the 41 segments. Initial exchange coefficients were obtained from previous modeling of the Port Tobacco River and adjusted during the calibration of the model. Final values were

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[2] 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 |

0.001m^2/day for segments 12 through 41; 2.0 m^2/day for segments 10 and 11; 4.0 m^2/day for segment 9; 10.0 m^2/day for segments 7 and 8; 20.0 m^2/day for segments 1 through 6. Freshwater flows and nonpoint source loadings are taken into consideration by dividing the drainage basin into 16 subwatersheds and assuming that these flows and loadings are direct inputs to the PTEM (Figure A9 and Table A3). The watersheds surrounding the three tributaries that receive STP discharges, are also subdivided, and the loads are input directly into the tributaries.

Freshwater Flows

The low and average flows for the 16 subwatersheds in the Port Tobacco basin were estimated using multiple regression. For estimating low flow, flow data at two stations HOG004 and UWV0019 were used along with land use data to develop a regression equation relating low flow to land use. Low flow for those areas which were not previously monitored were then estimated using the regression equation. A similar approach was taken for average flow, however there was no average flow data available for the basin. To overcome this, USGS gages in several nearby basins were identified and analyzed to determine long term average daily flow. Land use information was then used to derive a regression equation relating these flows to land use acres within the basins (R^2=0.90). This equation was then applied to the subwatersheds of Port Tobacco to estimate average flows.

Point and Nonpoint Source Loadings

There are four point source nutrient loads that discharge directly or indirectly into the Port Tobacco River. The La Plata STP, the Mt. Carmel STP, and the Thunderbird Apartments STP all discharge into tributaries of the Port Tobacco River. The STP at Charles Community College discharges directly into the River. The point source loadings used in the calibration of the model were calculated by averaging the August 1984 data for each STP (Table A4).

The nonpoint source loadings for the calibration of the model were calculated using data from two water quality stations within the Port Tobacco Basin (Stations HOG004 and UWV0019). HOG004 represented a mostly forested watershed. UWV0019 represented a mostly urban watershed. Several sets of data for each station were averaged. That average loading was distributed across the watershed. When the values obtained from this process were examined it was found that the organic nitrogen and nitrate values were low according to monitoring data from numerous small watersheds in the state. Thus, the loads for organic nitrogen and nitrate were adjusted for the calibration of the model (Table A5). The nonpoint source loads reflect atmospheric deposition, loads coming from septic tanks, loads coming from urban development, agriculture, and forest land.

For both point and nonpoint sources, the concentrations of the nutrients nitrogen and phosphorus are modeled in their speciated forms. The WASP5 model simulates nitrogen as ammonia (NH_3), nitrate (NO23) and organic nitrogen (ON), and phosphorus as ortho-phosphate (PO_4) and organic phosphorus (OP). Ammonia, nitrate, and ortho-phosphate represent the dissolved forms of nitrogen and phosphorus. The dissolved forms of nutrients are more readily available for chemical processes such as algae growth, that can affect chlorophyll *a* levels and dissolved oxygen concentrations. The ratios of total nutrients to dissolved nutrients used in the model scenarios represent values that have been measured in the field.

Environmental Conditions

For application to the Port Tobacco River three environmental parameters were used for temperature, solar radiation, and photoperiod (Table A6).

Light extinction coefficients, K_e in the water column were derived from the Secchi depth measurements using the following equation:

$$K_e = \frac{1.75}{D_s}$$

where:

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

Table A6: Environmental Parameters

Parameter	**Value**
Solar radiation (*langleys / day*)	500.0
Photoperiod (fraction of a day)	0.6
Temperature (segments 1-11, ^{o}C)	28.0
Temperature (segments 12-41, ^{o}C)	21.4
Light extinction coefficient (segments 1-4, m^{-1})	4.16
Light extinction coefficient (segments 5-7, m^{-1})	6.23
Light extinction coefficient (segments 8-41, m^{-1})	12.47

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 Potomac River (Clark and Roesh, 1978), (Thomann and Fitzpatrick, 1982) and of Mattawoman Creek (Panday and Haire, 1985, 1986). The kinetic Coefficients are listed in Table A7.

A phytoplankton settling rate velocity of 0.0224 *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 0.0432 *m/day*. In general, 50% of the nonliving organics were considered in the particulate form. Such assignments were borne out through model sensitivity analyses.

Initial Conditions

The initial conditions used in the model were as close to the observed values as possible. However, since the model was run for a long period of time (45 days) it was found that initial conditions did not impact the final results.

CALIBRATION & SENSITIVITY ANALYSIS

The EUTRO5 model was calibrated with August 1984 data. Table A4 and Table A5 show the point and nonpoint source loads and flows associated with the calibration input file. The calibration of the model is also represented as *Scenario 1* in the main document. Table A5 shows the flows at each of the boundary nodes. Figure A10 - A17 shows the results of the calibration run. 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 peak chlorophyll *a* concentrations and also the general trend (Figure A10). The model also captured the peak nitrate and phosphorus concentrations as well as their overall trend (Figure A15 and A12). It was able to replicate the organic nitrate trend although it did not capture the peak values because of the spread in the data (Figure A16).

A sensitivity analysis was performed to determine the effect of flow in the Port Tobacco System. The nonpoint source flows and corresponding loads were increased by a factor of four to test the sensitivity of the model during high flows. As shown in Figures A18 – A21, when the August freshwater flows are quadrupled, the system is almost pristine. This means that during high flow the system is flushed.

SYSTEM RESPONSE

The EUTRO5 model of the Port Tobacco River was applied to several different point and nonpoint source loading conditions under various stream flow conditions to project the impacts of nutrients on the eutrophication of the River. By modeling various stream flows, the model runs simulate seasonality, which is a necessary element of the TMDL development process.

Model Run Descriptions

The first model run represents the base case conditions of the stream during average stream flow. This run is also represented as *Scenario 2* in the main document. The nonpoint source loads for average year flows were calculated differently than for the calibration. These loads were determined using a simple land use/loading coefficient approach. The 16 subwatersheds in the Port Tobacco Basin were digitized and overlaid onto a land use map using ARC/INFO GIS. Next, the total nonpoint source load for each subwatershed was calculated summing all of the individual land use areas multiplied by the corresponding land use coefficients. The loading coefficients were based on average loading rates that are consistent with the Chesapeake Bay Program 1985 loading rates (U.S. EPA, 1991)**,** and account for both atmospheric deposition and loads from septic tanks. Finally, the nonpoint source loads were flow weighted using the flow determined previously. The nonpoint source loads and flows used in this scenario can be seen in Table A8. The point source loads at the point sources, represent the 1985 average annual point source flow multiplied by the corresponding concentration. The flows and concentrations were obtained from the 1985 DMRs stored in MDE's point source database. The total point source loads and flows can be seen in Table A9.

The second model run represented final conditions for the case of average stream flow. This run is also represented as *Scenario 4* in the main document. The total nonpoint source loads were calculated using the same methodology described in the first model scenario. The year 2000 loading rates were based on the results of the Chesapeake Bay Model (U.S. EPA, 1991), and account for loads from both atmospheric depositions and septic tanks. In addition, a 3% MOS was applied to the nonpoint source loads. The total nonpoint source loads and flows can be seen in Table A10. Total point source loads for the average annual conditions made up the balance of the total allowable load. Modeling input assumed that BNR and CPR would be implemented at major point sources under anticipated average annual concentrations. Details of this modeling activity are described further in the technical memorandum entitled *Significant Nutrient Point Sources in the Port Tobacco Watershed.*

The third scenario represented final conditions for low stream flow. This run is also represented as *Scenario 3* in the main document. Total nonpoint source loads were simulated as 1984 summer base flow nutrient concentrations plus a 3% margin of safety (MOS). These flows and loads represent actual field values measured in the Port Tobacco Basin during August, 1984. It was determined that August represents a low flow month, and extensive field expertise was used to conclude that the August 1984 low flow values measured in the field represent what is actually seen during critical low flow periods (Table A11). They represents conservative estimates given that the 1984 loads predate the implementation of nonpoint source nutrient reduction controls for the Lower Potomac Tributary Strategy Basin which began in 1985. Total point source loads for the summer low flow critical conditions made up the balance of the total allowable load. Modeling input assumed that BNR and CPR would be implemented at major point sources under anticipated summer operating conditions. The minor point sources were assumed to operate without BNR or CPR during the same conditions. Details of this modeling activity are described further in the technical memorandum entitled *Significant Nutrient Point Sources in the Port Tobacco Watershed.*

The PTEM calculates the daily average dissolved oxygen concentrations in the stream. This is not necessarily protective of water quality when one considers the effects of diurnal dissolved oxygen variation due to photosynthesis and respiration of algae. The photosynthetic process centers about the chlorophyll containing algae, which utilize radiant energy from the sun to convert water and carbon dioxide into glucose, and release oxygen. Because the photosynthetic process is dependent on solar radiant energy, the production of oxygen proceeds only during daylight hours. Concurrently with this production, however, the algae require oxygen for respiration, which can be considered to proceed continuously. Minimum values of dissolved oxygen usually occur in the early morning predawn hours when the algae have been without light for the longest period of time. Maximum values of dissolved oxygen usually occur in the early afternoon. The diurnal range (maximum minus minimum) may be large and if the daily mean level of dissolved oxygen is low, minimum values of dissolved oxygen during a day may approach zero and hence create a potential for fish kill. The diurnal dissolved oxygen variation due to photosynthesis and respiration can be estimated based on the amount of chlorophyll *a* in the water. The equations used to calculate the diurnal dissolved oxygen are shown below, and results from the critical low flow model run is given at the end of the model results section:

Diurnal Dissolved Oxygen Calculations

$$p_{av} = p_s G(I_a) \qquad \text{where}: p_s = 0.25P$$

$$G(I_a) = \frac{2.718 f}{K_e H}\left[e^{-a_1} - e^{-a_0}\right] \qquad \text{where}: a_1 = \frac{I_a}{I_s} e^{-K_e z} \quad , \quad a_o = \frac{I_a}{I_s}$$

$$\frac{\Delta}{P_{av}} = \frac{\left(1 - e^{-K_a f T}\right)\left(1 - e^{-K_a T (1-f)}\right)}{f\, K_a \left(1 - e^{-K_a T}\right)}$$

Where:

p_{av} = average gross photosynthetic production of dissolved oxygen (*mg O_2/L day*)
p_s = light saturated rate of oxygen production (*mg O_2/L day*)
P = phytoplankton chlorophyll *a (mg/l*)
$G(I_a)$ = light attenuation factor
f = photoperiod (fraction of a day)
H = the total depth (*m*)
K_e = the light extinction coefficient (m^{-1})
I_s = saturation light intensity for phytoplankton (*langly/day*)
I_a = average solar radiation during the day (*langly/day*)
z = depth (*m*)
Δ = dissolved oxygen variation due to phytoplankton
K_a = reaeration coefficient (day^{-1})
T = period **(Thomman and Mueller, 1987)**

Model Results

1. *Model Run 1:* Assumes average stream flow conditions. Assumes the 1985 average annual nonpoint source loads, and 1985 average annual point source loads for the point sources.

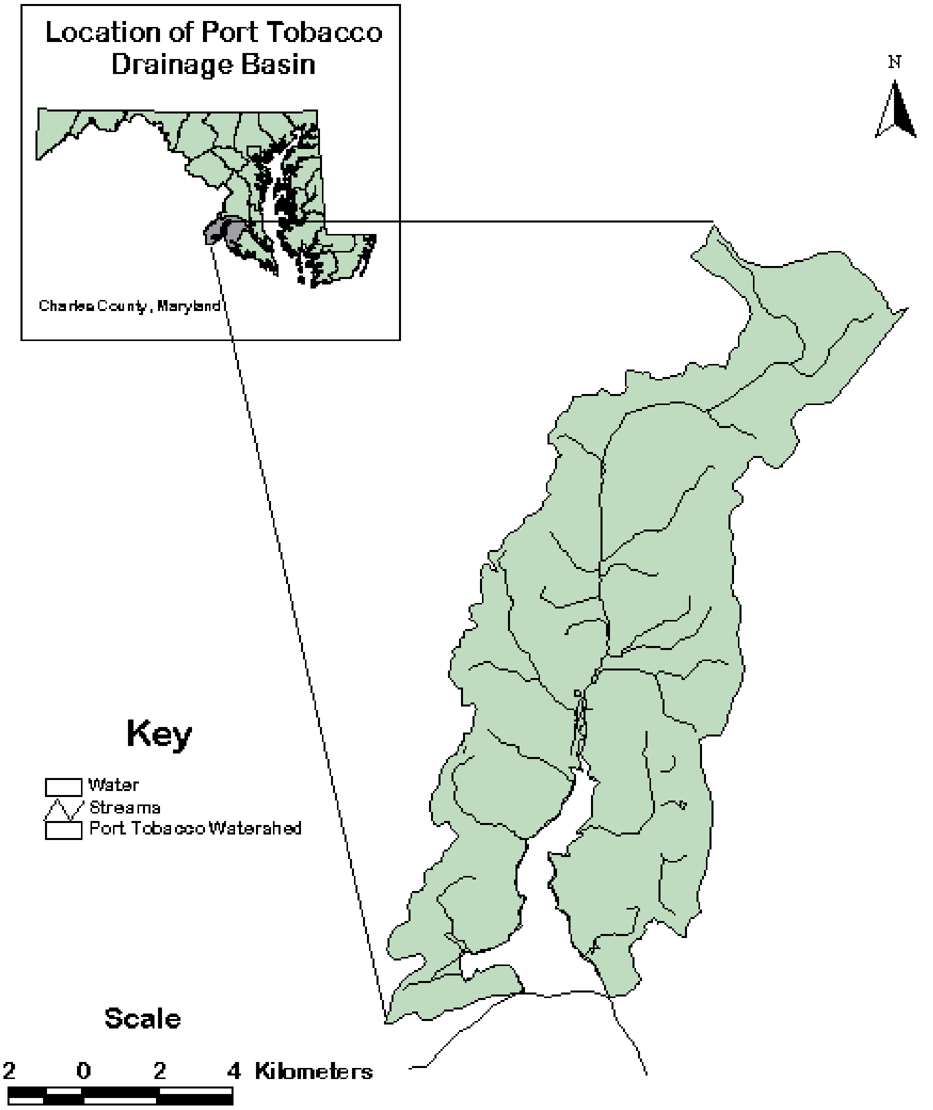
2. *Model Run 2:* Assumes average stream flow conditions. Assumes the 2000 average annual nonpoint source loads plus a 3% margin of safety. Assumes that point source loads for the average annual conditions make up the balance of the total allowable load. Assumes that BNR and CPR will be implemented at the major point sources under anticipated average annual concentrations.

3. *Model Run 3:* Assumes low stream flow conditions. Assumes 1984 summer low flow nonpoint source loads plus a 3% margin of safety. Assumes point source loads for the summer low flow critical conditions make up the balance of the total allowable load. Assumes that BNR and CPR will be implemented at the major point sources under anticipated summer operating conditions.

The results from the first model run and the calibration results can be seen in Figures A22-A25. The results from the second model run and the calibration results are shown in Figures A26-A29. It can be seen that the water quality of the system is significantly improved, compared to the calibration, under both of these loading conditions. This was expected from the results of the sensitivity analysis which showed when the nonpoint source flows and loads were quadruple the low flow (approximately double from average yearly flow), the system was restored. However, the 1984 data clearly shows that during summer months, when flows are low, there are elevated nutrient and chlorophyll *a* levels in the system.

For this reason, the model was used to project the water quality response under summer low flow conditions. The third model run incorporated summer nonpoint source loads plus a 3% margin of safety (MOS), and also used the maximum allowable STP flows and loads, including summer BNR and CPR. The water quality response resulting from this model run and the calibration are shown in Figures A30-A33. It can be seen that the water quality of the system improves under the third model run, summer baseflow loading conditions. During the critical conditions of summer low flow, the peak chlorophyll *a* values are reduced to below 52 µg/l. It must be noted that a summer BNR level of 6 mg/l must be maintained to achieve the desired chlorophyll level.

For model scenario 3, where there is the greatest potential for a diurnal dissolved oxygen problem, the variation due to photosynthesis and respiration was calculated. Half of the total variation was subtracted from the average dissolved oxygen concentration calculated by the model. The areas of greatest concern in the Port Tobacco were the locations where the chlorophyll *a* values are the largest, and the dissolved oxygen values are the lowest. The highest chlorophyll *a* value, 51.35 µg/l, occurred at model segment 10. The dissolved oxygen at that location was 8.265 mg/l. After the variation due to photosynthesis was subtracted, the dissolved oxygen concentration was reduced to 7.991 mg/l. The lowest dissolved oxygen concentration, 6.309 mg/l, occurred at model segment 20. After the variation due to photosynthesis was subtracted, the dissolved concentration was reduced to 6.290. Both of these final values are well above the water quality standard of 5.0 mg/l.



Prepared by:

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2500 Broening Highway
Baltimore, Maryland 21224

Figure A1: Port Tobacco Drainage Basin Location Map

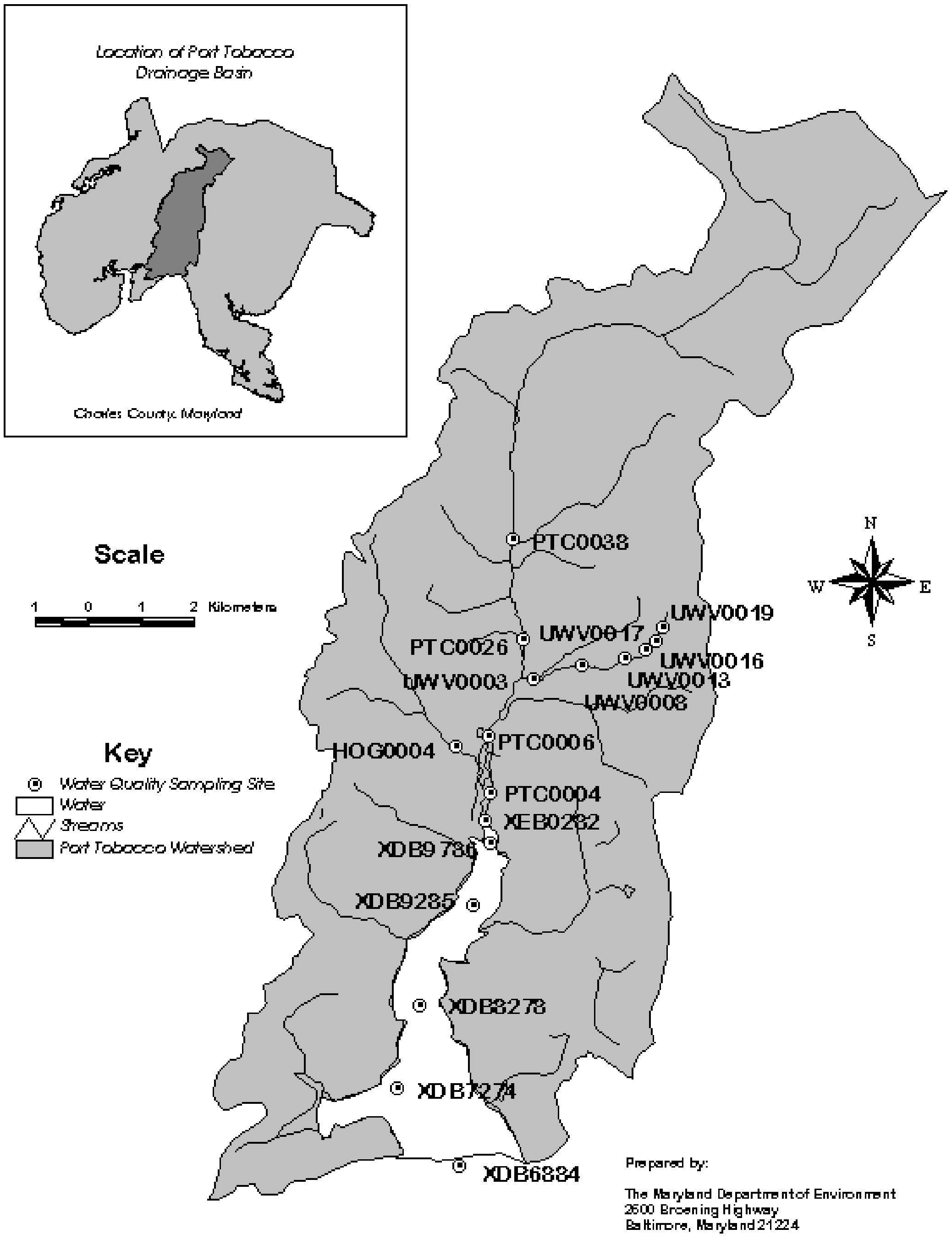


Figure A2: Location of Water Quality Sampling Sites in the Port Tobacco Drainage Basin

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 (mg/l as P)		Technicon Industrial Method # 376-75W/B; #329-74/B
Ortho-phosphate (mg/l as P)		Technicon Industrial Method # 155-71W
Chlorophyll a (ug/l)	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

Table A1: Field and Laboratory Protocals used to collect and Process the Water Quality Samples

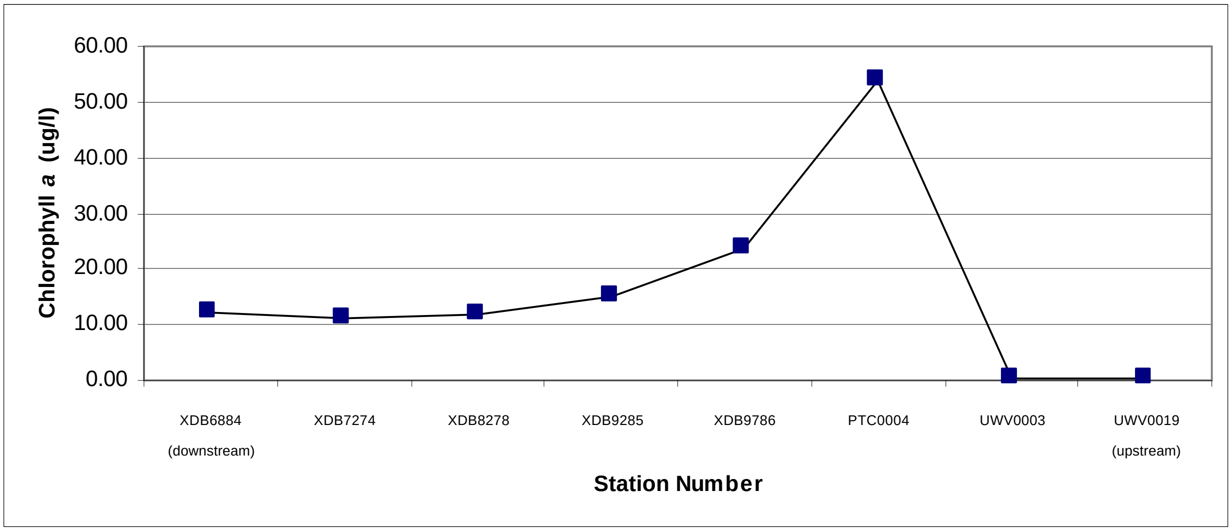


Figure A3: Chlorophyll *a* Longitudinal Profile

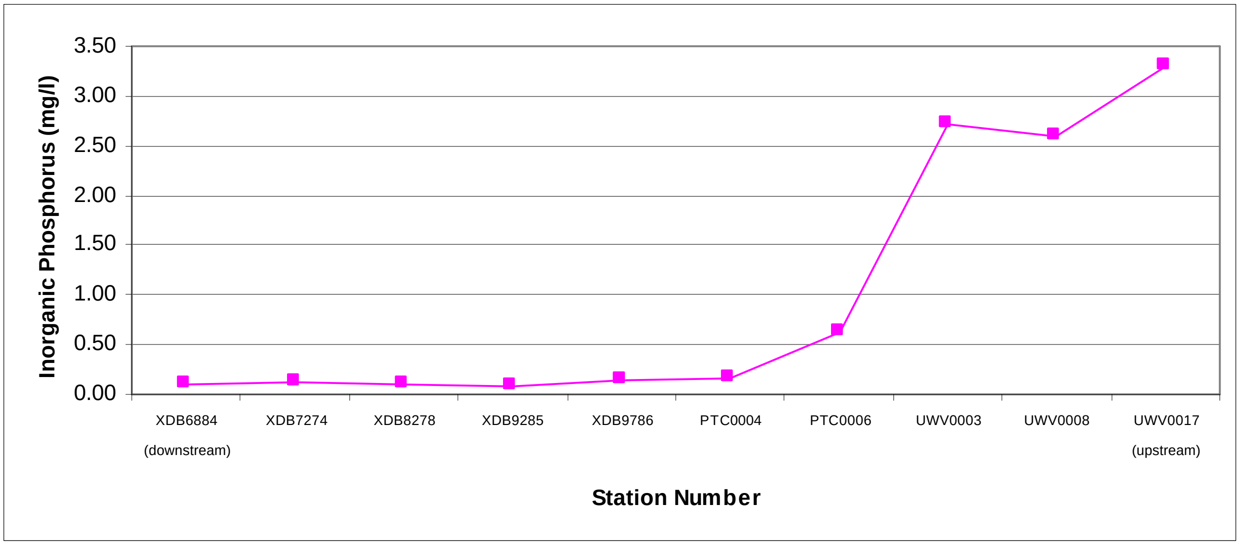


Figure A4: Inorganic Phosphorus Longitudinal Profile

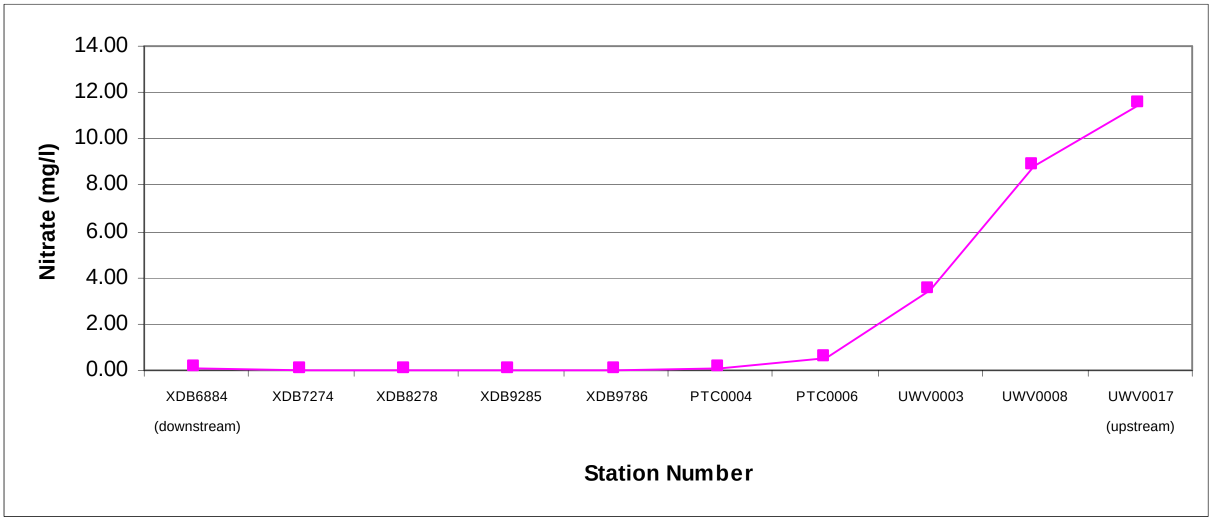


Figure A5: Nitrate Longitudinal Profile

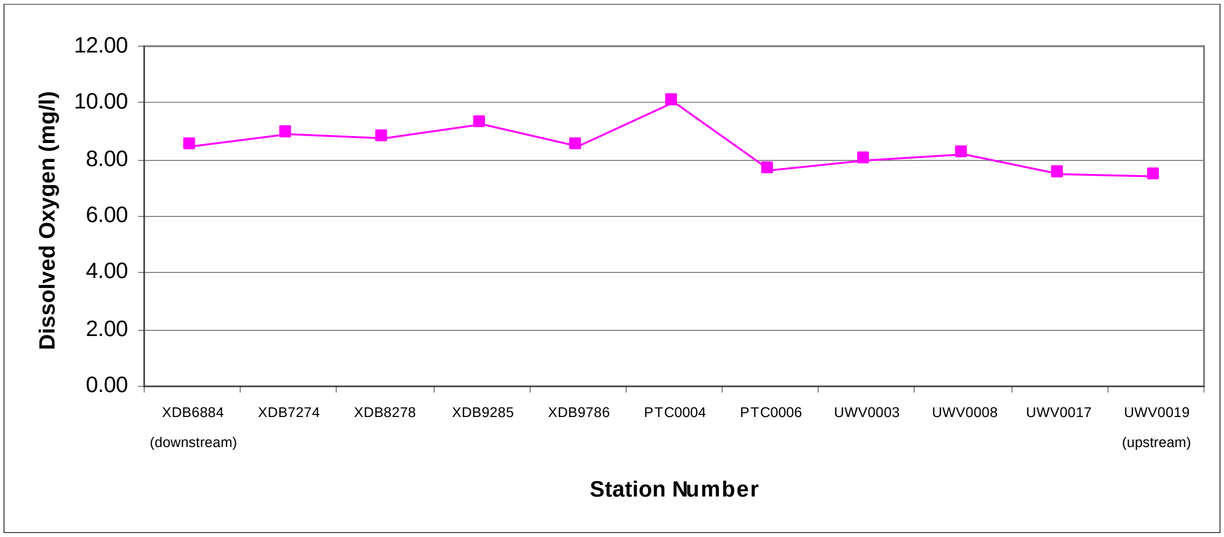


Figure A6: Dissolved Oxygen Longitudinal Profile

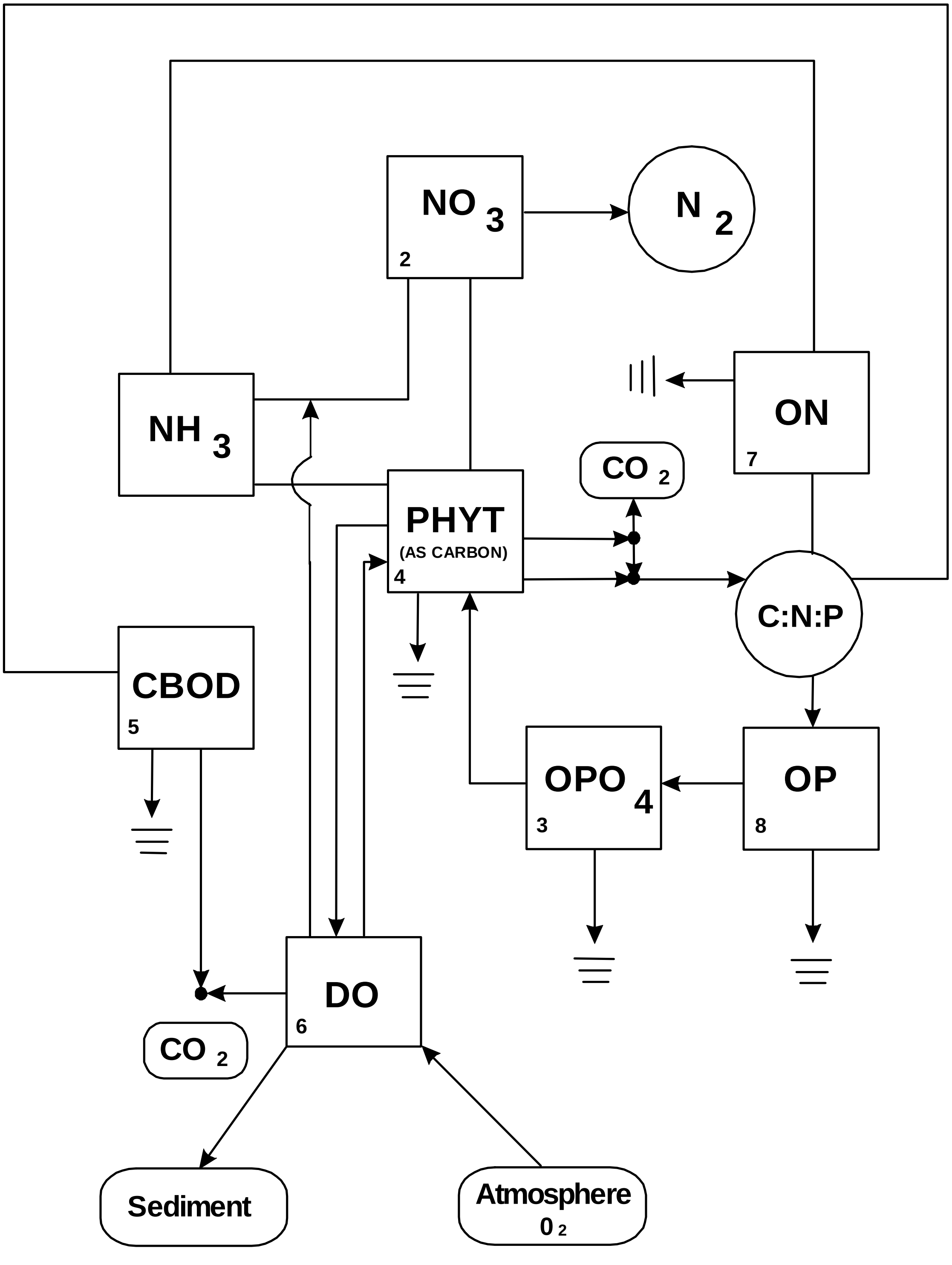


Figure A7: State Variables and Kinetic Interactions in EUTRO5

Port Tobacco
Modeling Domain

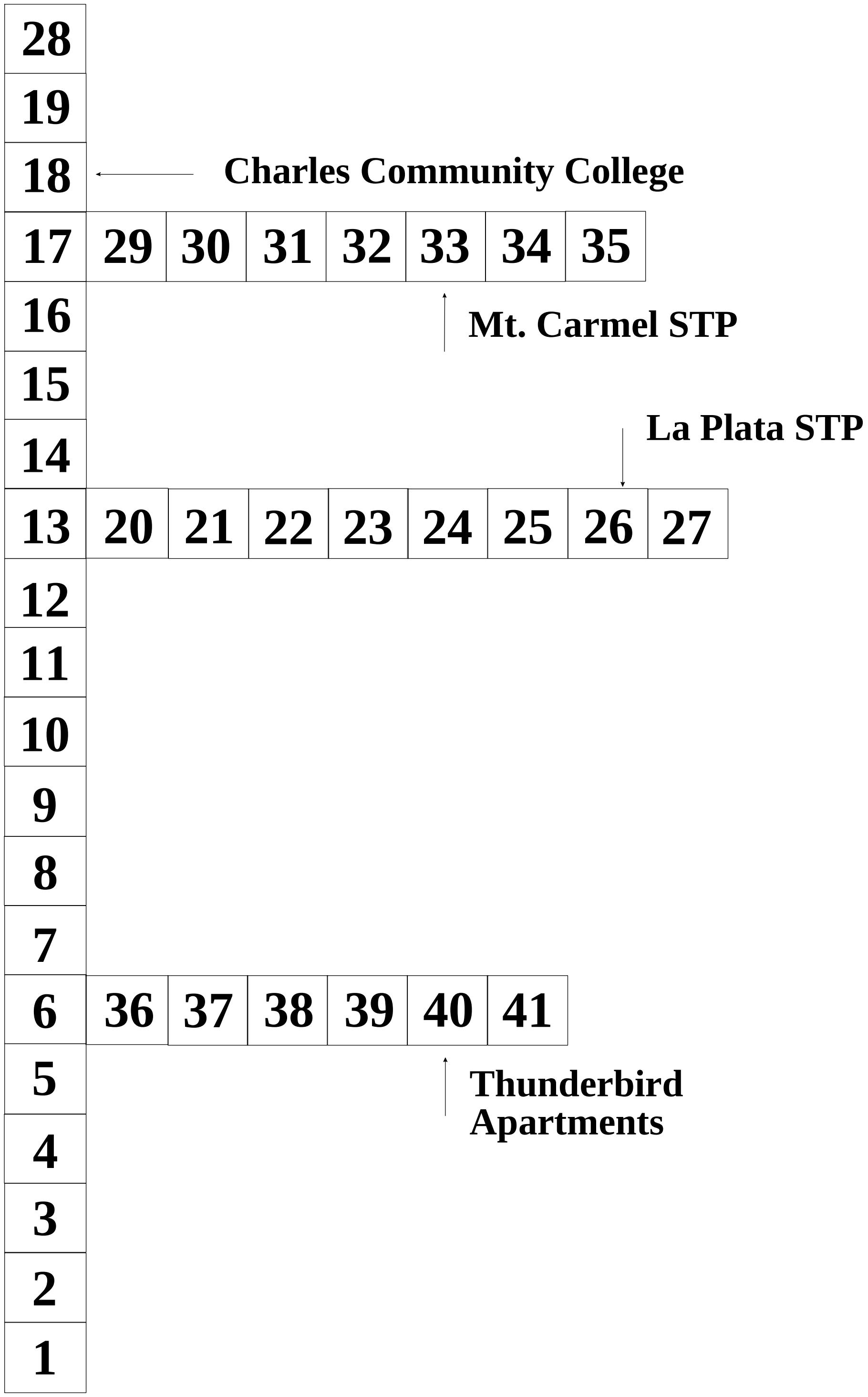


Figure A8: Model Domain of the Port Tobacco Eutrophication Model

Segment No.	Volume m^3	Characteristic Length m	Interfacial Area m^2
Main Branch			
28	225.00	243.00	1.00
19	225.00	212.50	1.00
18	550.00	487.50	1.00
17	870.00	853.50	1.00
16	870.00	853.50	1.00
15	600.00	548.50	1.00
14	870.00	396.00	4.00
13	500.00	451.00	4.00
12	705.00	702.00	4.00
11	54050.00	1067.00	54.00
10	54050.00	931.00	54.00
9	140466.00	706.00	173.60
8	280582.00	631.00	464.50
7	316129.00	754.00	480.40
6	680340.00	840.00	800.40
5	758620.00	758.00	914.00
4	807586.00	705.00	1177.20
3	1053811.00	919.00	1455.50
2	2577880.00	602.00	2312.80
1	2705296.00	726.00	3344.00
Mt. Carmel Tributary			
35	700.00	700.00	1.00
34	700.00	700.00	1.00
33	700.00	700.00	1.00
32	700.00	700.00	1.00
31	700.00	700.00	1.00
30	700.00	700.00	1.00
29	700.00	700.00	1.00
La Plata Tributary			
27	135.00	135.00	1.00
26	135.00	135.00	1.00
25	135.00	221.00	1.00
24	307.00	383.00	1.00
23	460.00	425.00	1.00
22	390.00	625.00	1.00
21	860.00	754.00	1.00
20	848.00	574.00	1.00
Thunderbird Tributary			
41	855.00	477.50	1.00
40	855.00	855.00	1.00
39	855.00	855.00	1.00
38	855.00	855.00	1.00
37	855.00	855.00	1.00
36	855.00	510.50	1.00

Table A2: Volumes, Characteristic Length, and Interfacial Area of the PTEM

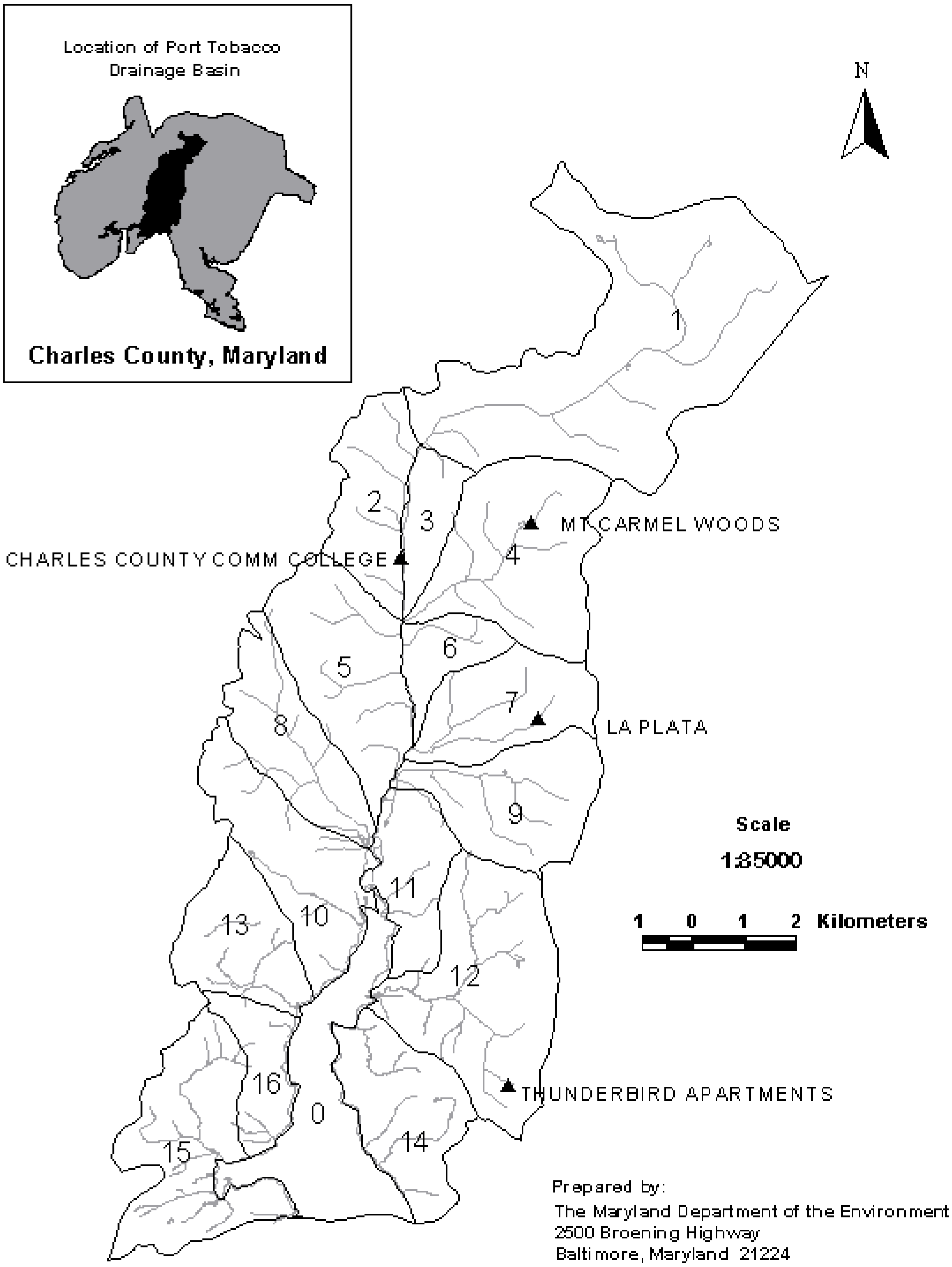


Figure A9: 16 Subwatersheds of the PTEM

Segment Number	Contributing Subwatershed
1	-
2	15 + (1/3)14 + (1/3)16
3	(1/3)14
4	(1/3)16
5	(1/3)14 + (1/3)16
6	13
7	(1/2)11
8	(1/2)10
9	11
10	-
11	8
12	9
13	-
14	-
15	-
16	5 + 6
17	-
18	Charles Comm. College STP
19	2 + 3
20	-
21	(1/2) 7
22	(1/10) 7
23	(1/10) 7
24	(1/10) 7
25	(1/10) 7
26	La Plata STP
27	(1/10) 7
28	1
29	-
30	-
31	-
32	-
33	Mt. Carmel STP
34	-
35	4
36	-
37	-
38	-
39	-
40	Thunberbird Apts. STP
41	12

Table A3: Inputs into the PTEM Segmentation

		La Plata	**Charles CC**	**Mt. Carmel**	**Thunderbird**
CBOD	*kg/d*	14.27	0.44	0.51	1.93
DO	*kg/d*	12.30	0.76	0.28	0.16
NH_3	*kg/d*	0.66	0.17	0.21	0.44
ON	*kg/d*	4.99	0.17	0.19	0.10
NO23	*kg/d*	32.70	1.63	0.15	0.05
PO_4	*kg/d*	9.50	0.37	0.37	0.19
OP	*kg/d*	1.38	0.02	0.03	0.04
Flow	m^3/s	0.0284	0.0018	0.0007	0.0004
Total Nitrogen	*kg/d*	38.36	1.97	0.55	0.58
Total Phosphorus	*kg/d*	10.87	0.39	0.40	0.23
Overall Total Nitrogen		***kg/d***	**41.45**		
Overall Total Phosphorus		***kg/d***	**11.89**		

Table A4: Point Source Nutrient Loadings used in the Calibration of the Model, August 1984

Segment Number	**Flow** mgd	**NH3** *kg/d*	**NO23** *kg/d*	**ON** *kg/d*	**PO4** *kg/d*	**OP** *kg/d*
41	0.096	0.19	4.57	7.64	0.83	0.66
35	0.075	0.15	3.58	6.00	0.65	0.52
27	0.003	0.01	0.14	0.24	0.03	0.02
25	0.003	0.01	0.14	0.24	0.03	0.02
24	0.003	0.01	0.14	0.24	0.03	0.02
23	0.003	0.01	0.14	0.24	0.03	0.02
22	0.003	0.01	0.14	0.24	0.03	0.02
21	0.016	0.03	0.76	1.27	0.14	0.11
28	0.185	0.37	8.81	14.74	1.60	1.28
19	0.011	0.02	0.53	0.88	0.10	0.08
16	0.001	0.00	0.07	0.11	0.01	0.01
12	0.032	0.06	1.52	2.55	0.28	0.22
11	0.040	0.08	1.91	3.20	0.35	0.28
9	0.007	0.01	0.35	0.59	0.06	0.05
8	0.036	0.07	1.70	2.85	0.31	0.25
7	0.036	0.07	1.71	2.87	0.31	0.25
6	0.045	0.09	2.15	3.59	0.39	0.31
5	0.005	0.01	0.24	0.40	0.04	0.03
4	0.003	0.01	0.14	0.24	0.03	0.02
3	0.003	0.01	0.14	0.24	0.03	0.02
2	0.070	0.14	3.33	5.57	0.61	0.48
Totals	**0.677**	**1.35**	**32.24**	**53.93**	**5.86**	**4.69**
			Total Nitrogen		**87.51**	
			Total Phosphorus		**10.55**	

Table A5: Nonpoint Source Nutrient Flows and Loads used in the Calibration of the Model, August 1984

(Note: Calibration of the model is the same as *Scenario 1* in the main document)

Constant	Code	Value
Nitrification rate	K12C	0.08 *day* -1 at 20^{o} C
temperature coefficient	K12T	1.08
Denitrification rate	K20C	0.08 *day* -1 at 20^{o} C
temperature coefficient	K20T	1.08
Saturated growth rate of phytoplankton	K1C	2.0 *day* -1 at 20^{o} C
temperature coefficient	K1T	1.08
Endogenous respiration rate	K1RC	0.025 *day* -1 at 20^{o} C
temperature coefficient	K1RT	1.045
Nonpredatory phytoplankton death rate	K1D	0.025 *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*-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	0.5
phosphorus	FOP	0.5
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		0.0224 *m/day*
Inorganics settling velocity		0.0432 *m/day*

Table A7: Kinetic Coefficients used in the PTEM

<u>Results of the Calibration of the Model</u>

Figure 10A: Chlorophyll *a* vs. River Kilometers

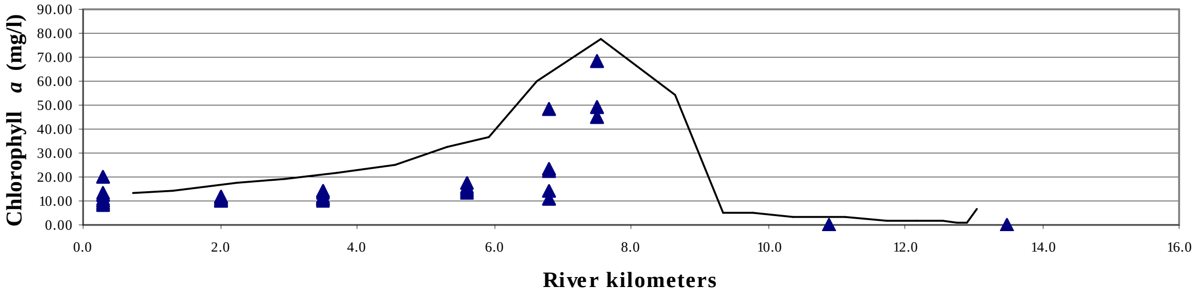


Figure 11A: Dissolved Oxygen vs. River Kilometers

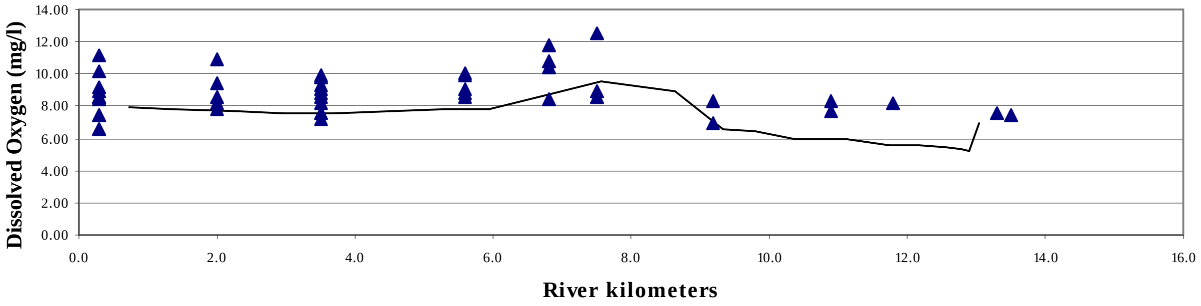


Figure 12A: Ortho-Phosphate vs. River Kilometers

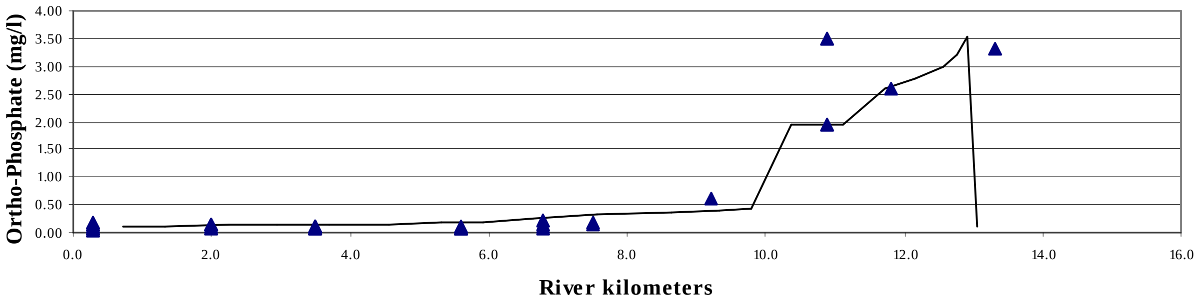


Figure 13A: Organic Phosphorus vs. River Kilometers

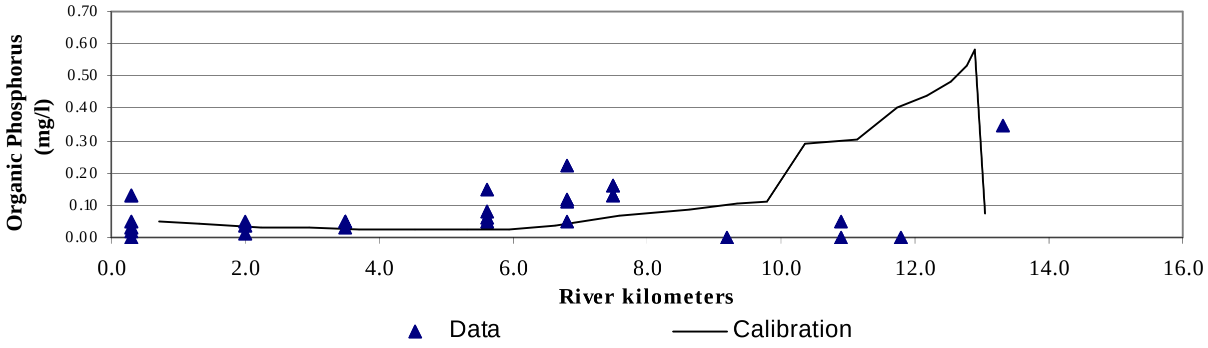


Figure 14A: Ammonia vs. River Kilometers

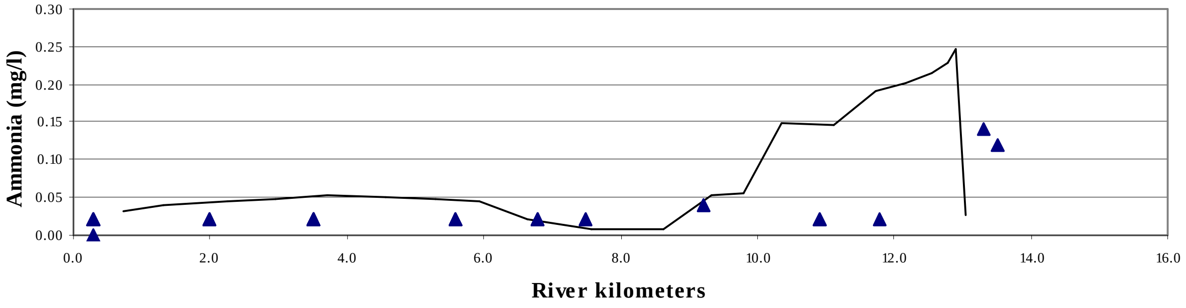


Figure 15A: Nitrite/ate vs. River Kilometers

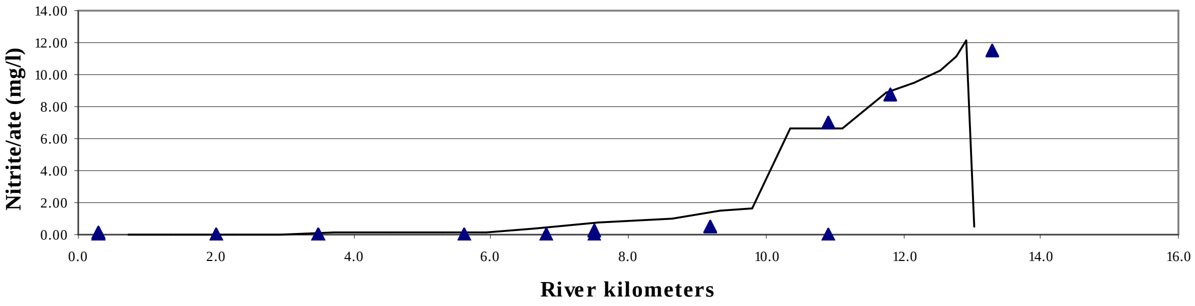


Figure 16A: Organic Nitrogen vs. River Kilometers

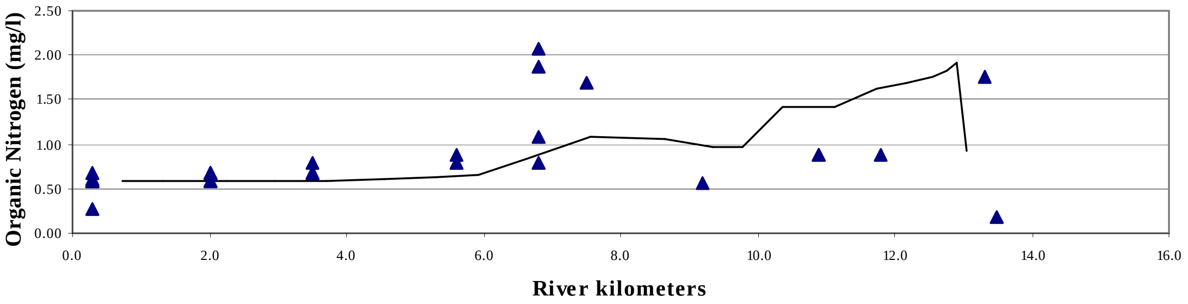
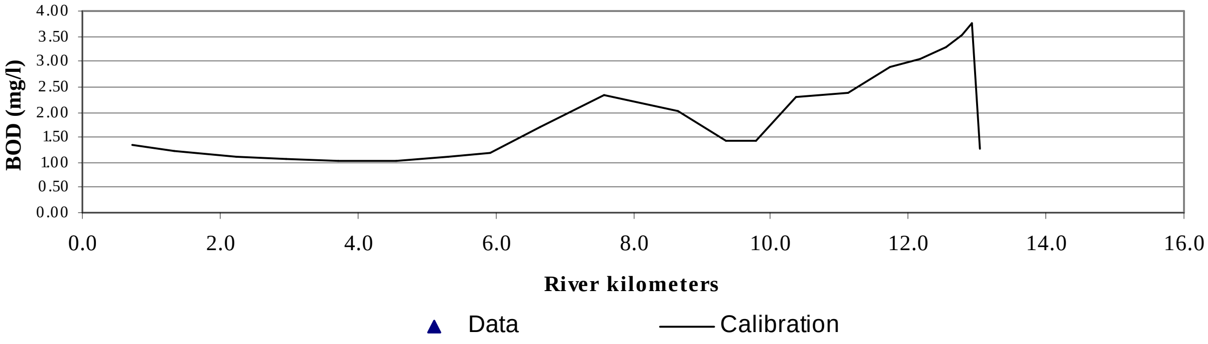


Figure 17A: BOD vs. River Kilometers



Results of the Sensitivity Analysis

Figure A18: Total Nitrogen vs. River Kilometers

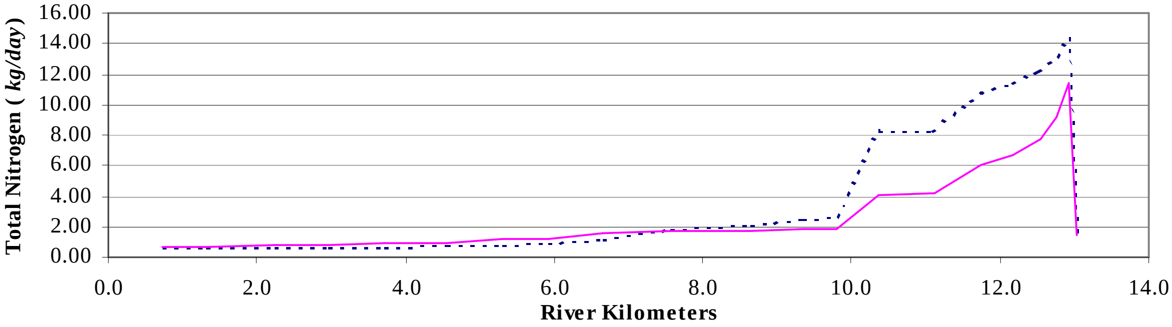


Figure A19: Total Phosphorus as. River Kilometers

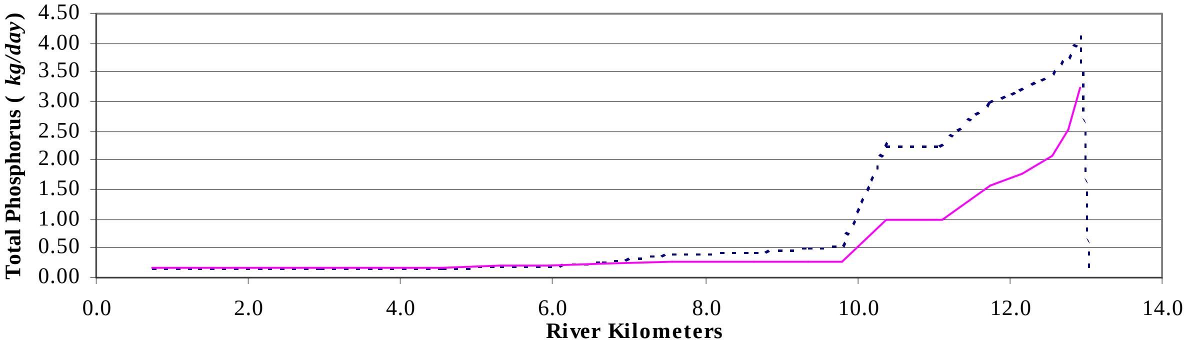


Figure A20: Chlorophyll *a* vs. River Kilometers

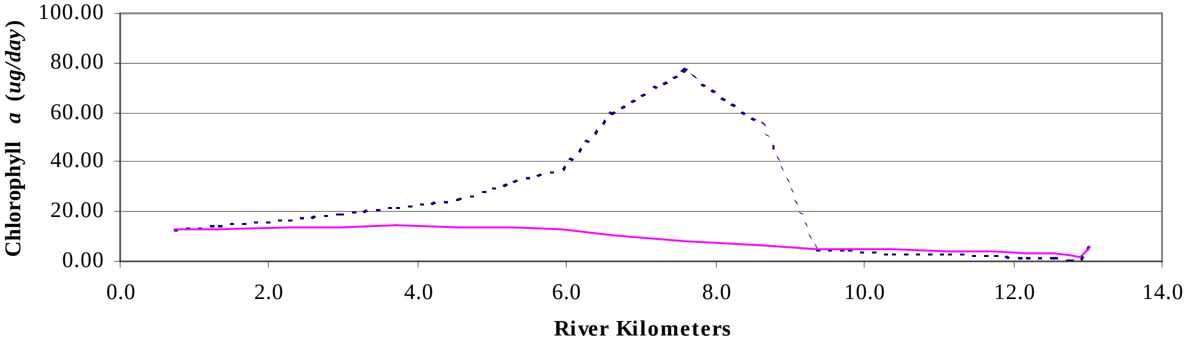
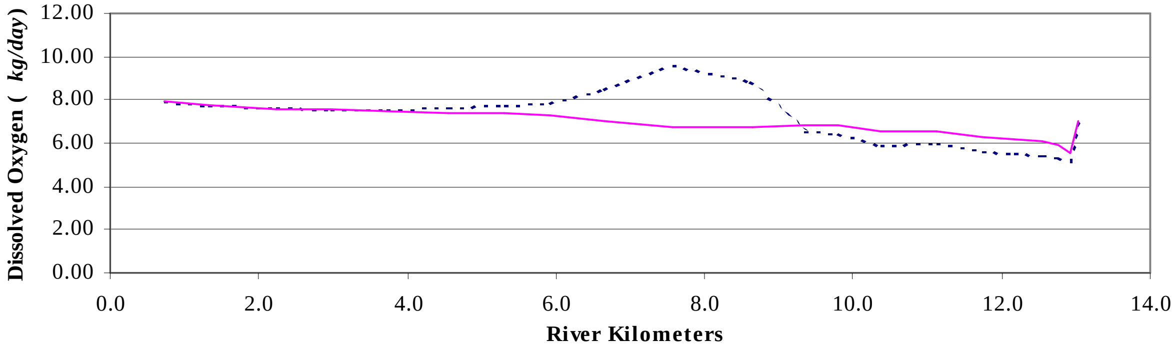


Figure A21: Dissolved Oxygen vs. River Kilometers



- - - - Calibration ——— Calibration with Quadrupled Flow

Segment Number	Flow m^3/s	Total Nitrogen kg/d	Total Phosphorus kg/d
2	0.126	21.50	1.33
3	0.003	5.10	0.36
4	0.006	2.39	0.17
5	0.009	7.48	0.53
6	0.194	7.69	0.41
7	0.054	5.60	0.32
8	0.054	5.60	0.32
9	0.037	6.86	0.43
11	0.055	8.03	0.40
12	0.059	13.10	0.85
16	0.068	21.75	1.44
19	0.011	14.03	0.87
21	0.044	6.00	0.40
22	0.009	1.13	0.08
23	0.009	1.13	0.08
24	0.009	1.13	0.08
25	0.009	1.13	0.08
27	0.009	1.13	0.08
28	0.259	38.55	2.25
35	0.125	16.70	1.00
41	0.132	16.35	0.87
Totals	**1.281**	**202.34**	**12.32**

Table A8: Model Run 1, 1985 Average Annual Nonpoint Source Flows and Nutrient Loads

		La Plata	Charles CC	Mt. Carmel	Thunderbird
CBOD	*kg/d*	21.61	0.32	0.28	1.67
DO	*kg/d*	15.13	0.68	0.21	0.15
NH_3	*kg/d*	2.75	0.15	0.13	0.41
ON	*kg/d*	7.31	0.15	0.14	0.09
NO23	*kg/d*	44.41	1.47	0.11	0.05
PO_4	*kg/d*	6.02	0.33	0.10	0.18
OP	*kg/d*	1.55	0.02	0.02	0.03
Flow	m^3/s	0.0350	0.0016	0.0005	0.0004
Total Nitrogen	*kg/d*	54.46	1.77	0.37	0.55
Total Phosphorus	*kg/d*	7.57	0.35	0.13	0.21
Overall Total Nitrogen	***kg/d***	**57.15**			
Overall Total Phosphorus	***kg/d***	**8.26**			

Table A9: Model Run 1, 1985 Average Annual Point Source Flows and Nutrient Loads

(Note: Model Run 1 is the same as *Scenario 2* in the main document)

Segment Number	**Flow** m^3/s	**Total Nitrogen** ***kg/d***	**Total Phosphorus** ***kg/d***
2	0.126	25.84	1.765
3	0.003	4.60	0.314
4	0.006	2.22	0.151
5	0.009	6.82	0.466
6	0.194	11.66	0.796
7	0.054	7.94	0.542
8	0.054	7.94	0.542
9	0.037	9.22	0.629
11	0.055	12.48	0.853
12	0.059	14.50	0.991
16	0.068	22.62	1.544
19	0.011	16.23	1.108
21	0.044	6.06	0.414
22	0.009	1.21	0.083
23	0.009	1.21	0.083
24	0.009	1.21	0.083
25	0.009	1.21	0.083
27	0.009	1.21	0.083
28	0.259	49.89	3.407
35	0.125	20.93	1.430
41	0.132	24.78	1.692
Totals	**1.281**	**249.806**	**17.060**

Table A10: Model Run 2, Year 2000 Average Annual Nonpoint Source Flows and Nutrient Loads plus a 3% MOS

(Note: Model Run 2 is the same as *Scenario 4* in the main document)

Segment Number	Flow m^3/s	Total Nitrogen *kg/d*	Total Phosphorus *kg/d*
2	0.096	12.764	1.539
3	0.075	10.022	1.208
4	0.003	0.399	0.048
5	0.003	0.399	0.048
6	0.003	0.399	0.048
7	0.003	0.399	0.048
8	0.003	0.399	0.048
9	0.016	2.130	0.257
11	0.185	24.641	2.971
12	0.011	1.469	0.177
16	0.001	0.186	0.022
19	0.032	4.259	0.513
21	0.040	5.350	0.645
22	0.007	0.980	0.118
23	0.036	4.766	0.575
24	0.036	4.791	0.578
25	0.045	6.003	0.724
27	0.005	0.665	0.080
28	0.003	0.399	0.048
35	0.003	0.399	0.048
41	0.070	9.317	1.123
Totals	**0.677**	**90.138**	**10.867**

Table A11: Model Run 3, August 1984 Low flow Nonpoint Source Flows and Nutrient Loads plus a 3% MOS

(Note: Model Run 3 is the same as *Scenario 3* in the main document)

Figure A22: Total Nitrogen vs. River Kilometers

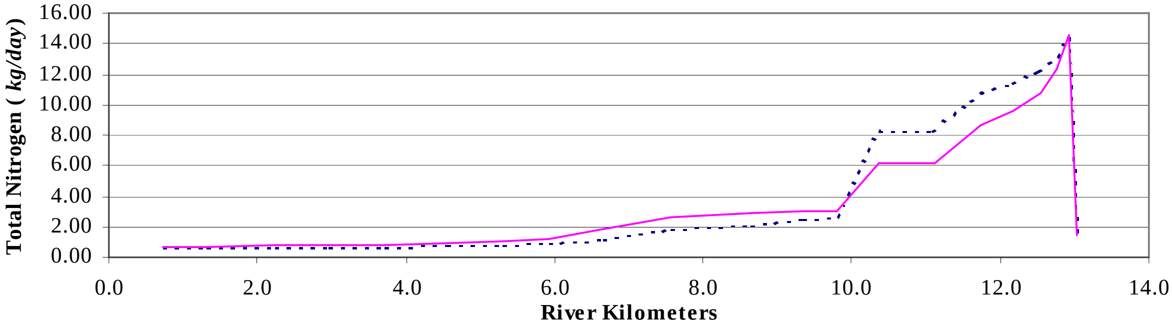


Figure A23: Total Phosphorus vs. River Kilometers

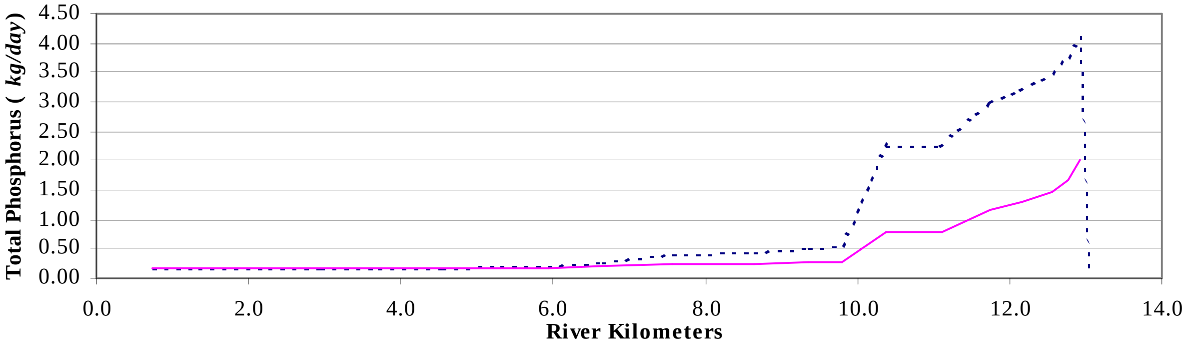


Figure A24: Chlorophyll *a* vs. River Kilometers

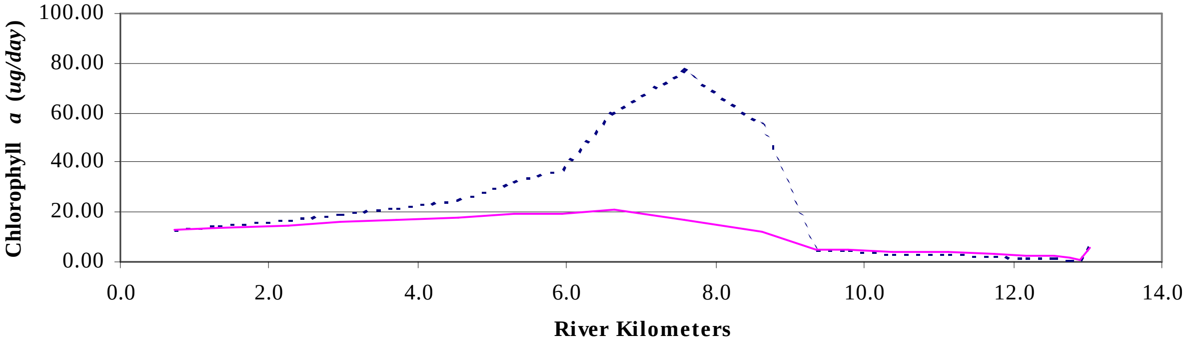


Figure A25: Dissolved Oxygen vs. River Kilometers

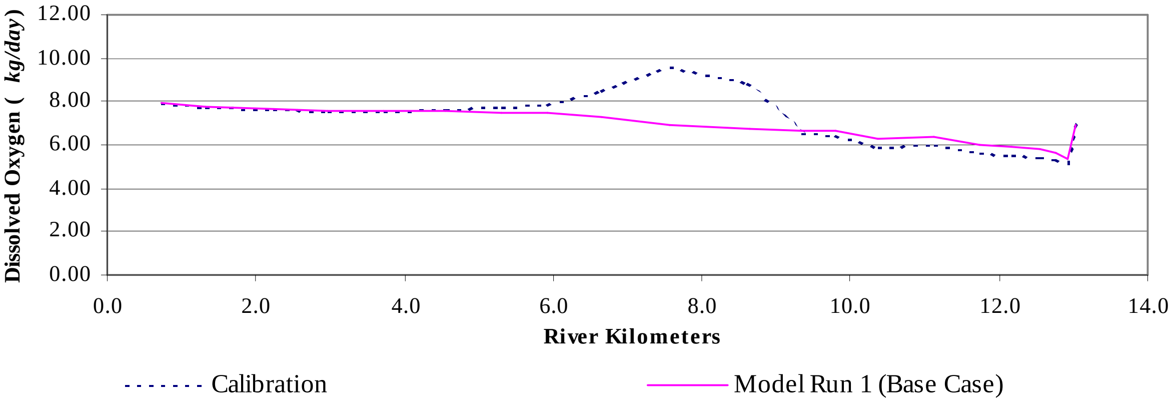


Figure A26: Total Nitrogen vs. River Kilometers

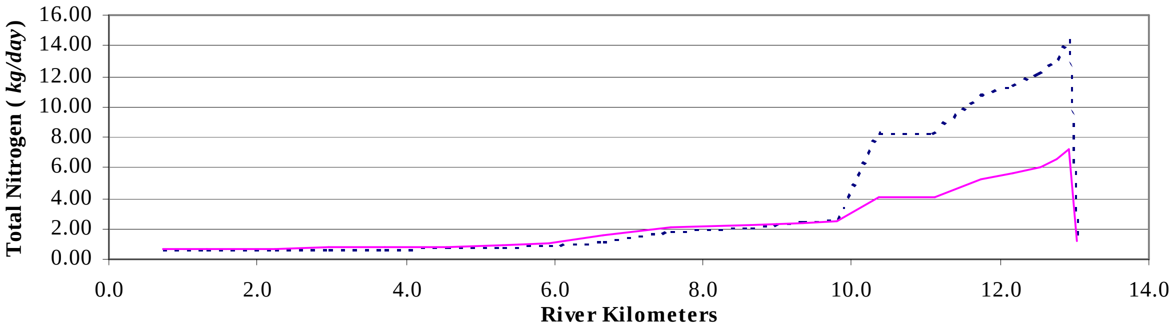


Figure A27: Total Phosphorus vs. River Kilometers

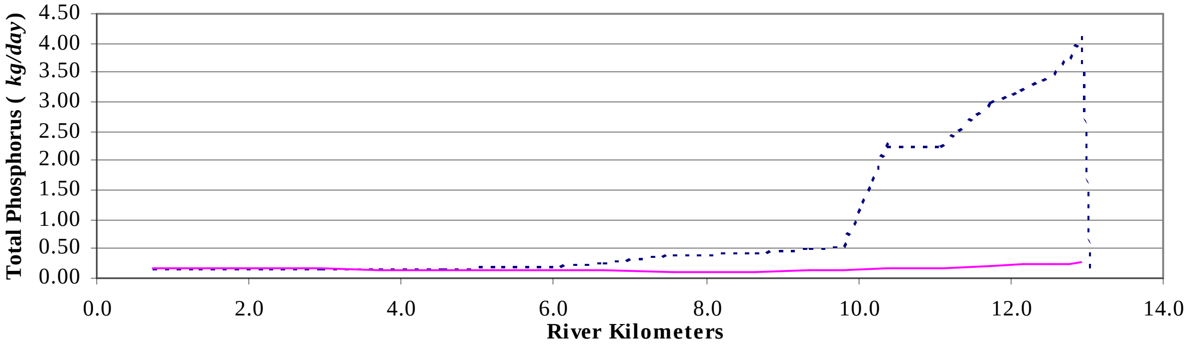


Figure A28: Chlorophyll *a* vs. River Kilometers

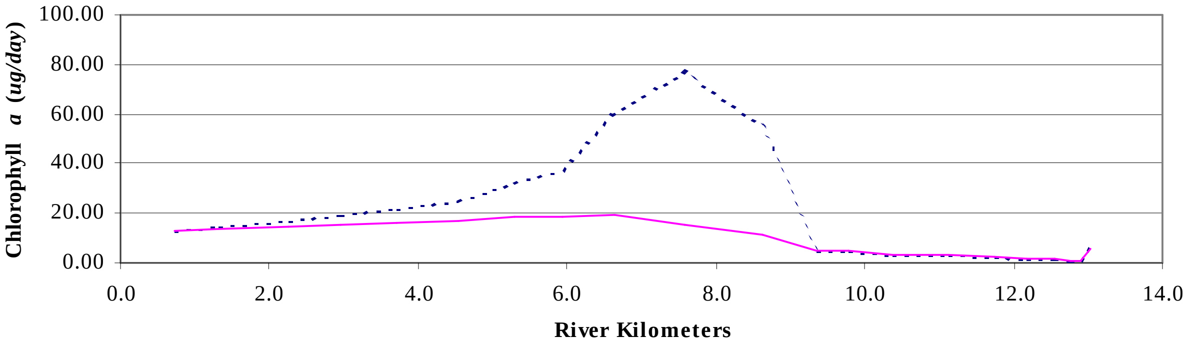


Figure A29: Dissolved Oxygen vs. River Kilometers

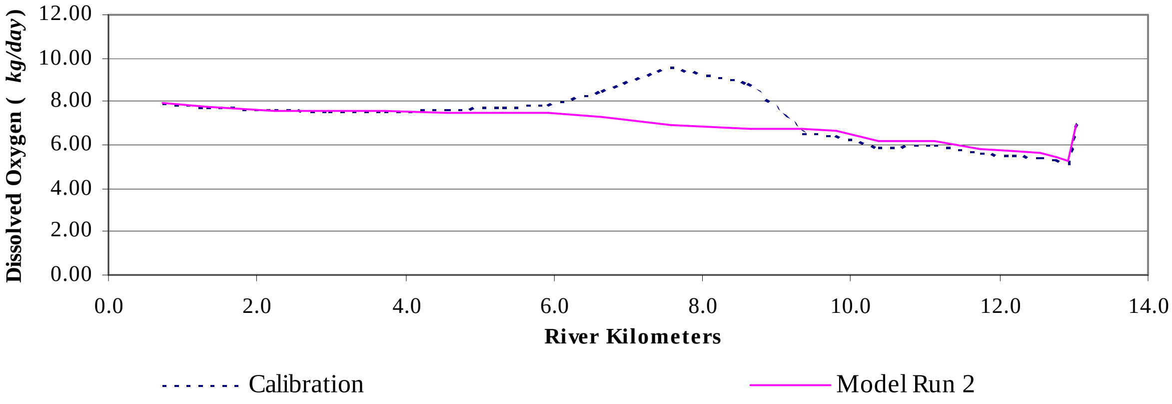


Figure A30: Total Nitrogen vs. River Kilometers

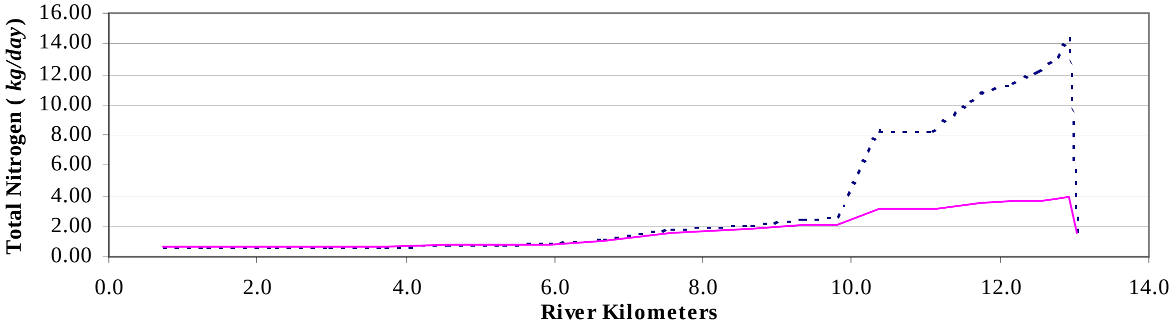


Figure A31: Total Phosphorus vs. River Kilometers

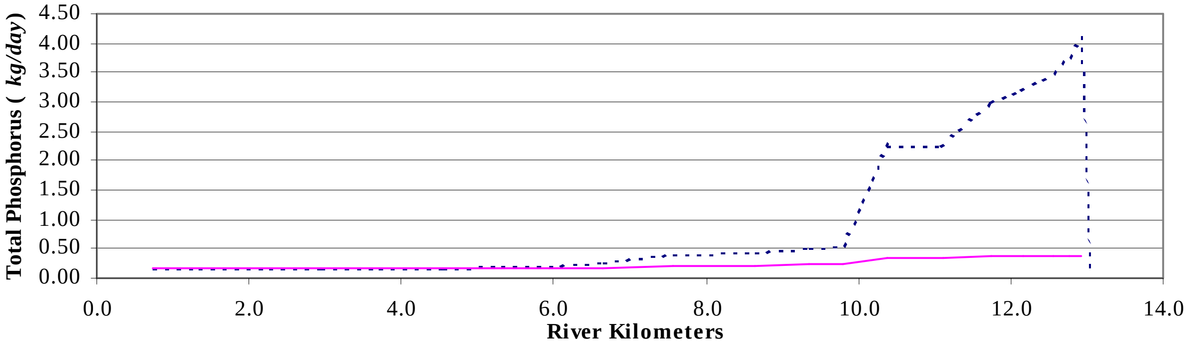


Figure A32: Chlorophyll *a* vs. River Kilometers

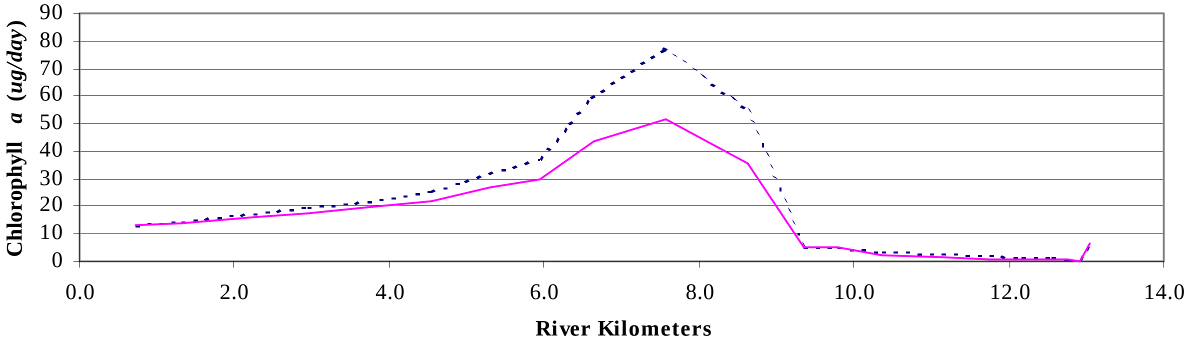
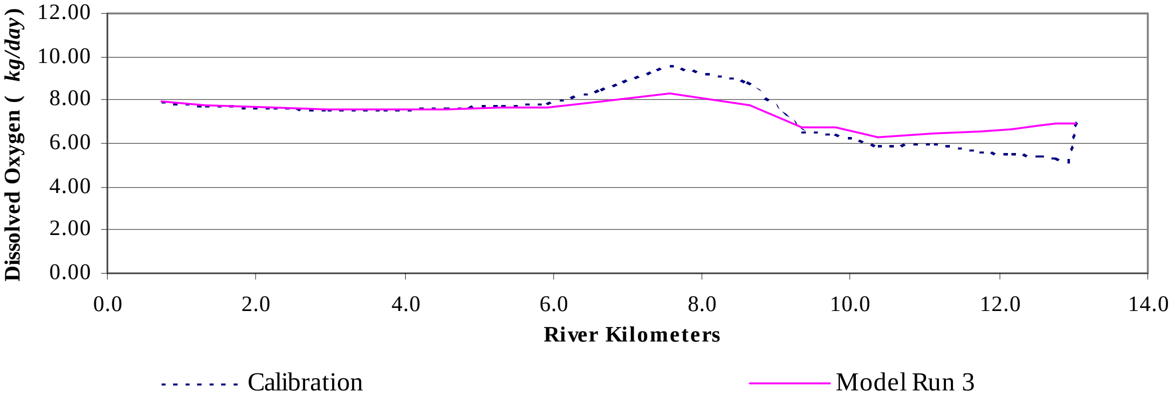


Figure A33: Dissolved Oxygen vs. River Kilometers



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