APPENDIX A

MODELING FRAMEWORK

The computational framework chosen for the modeling of water quality in Swan Creek was the Water Quality Analysis Simulation Program version 5.1 (WASP v.5.1). 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). EUTRO 5.1 is the component of WASP 5.1 applicable for modeling eutrophication, incorporating eight water quality constituents in the water column (Figure A1) and sediment bed.

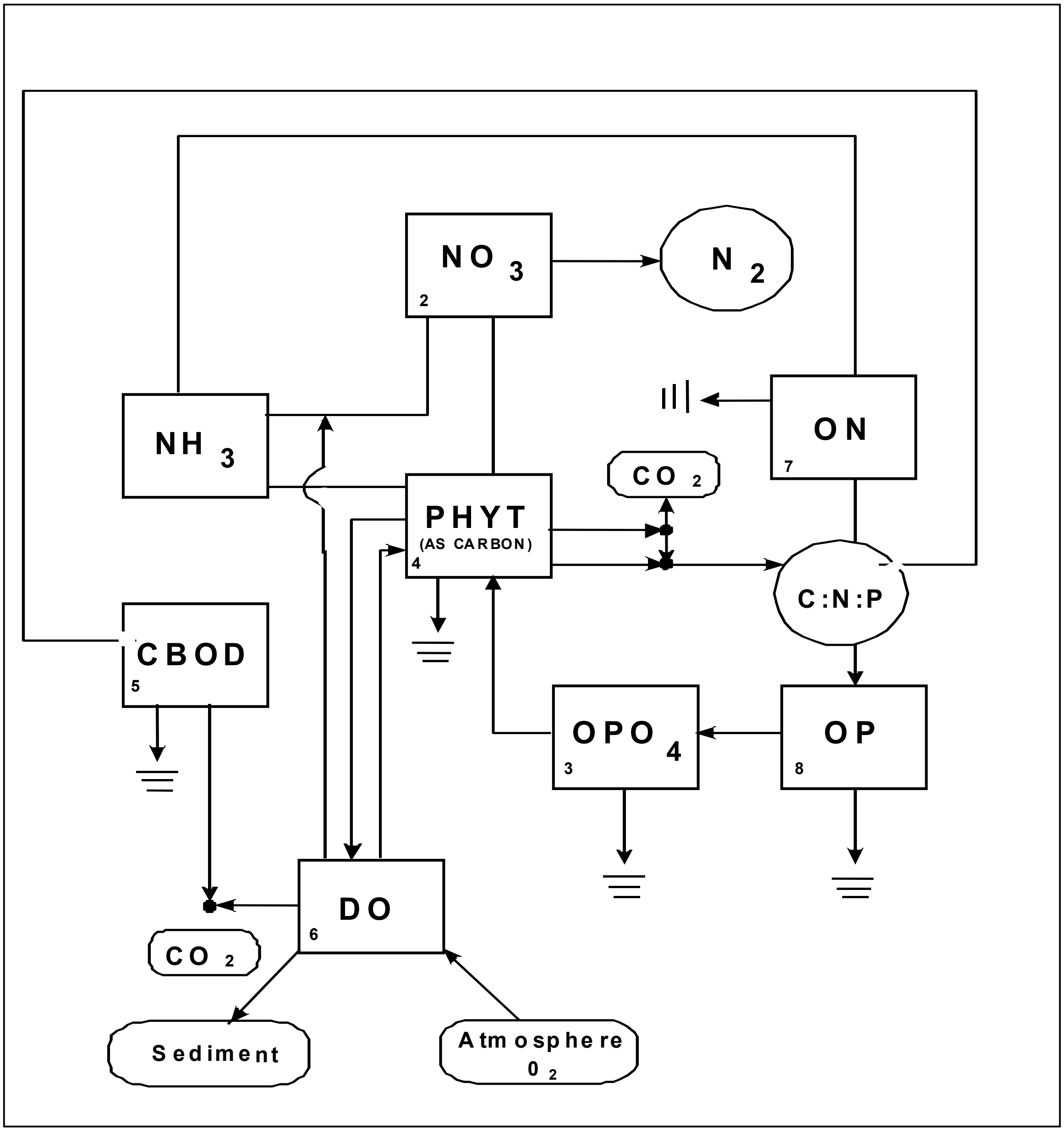


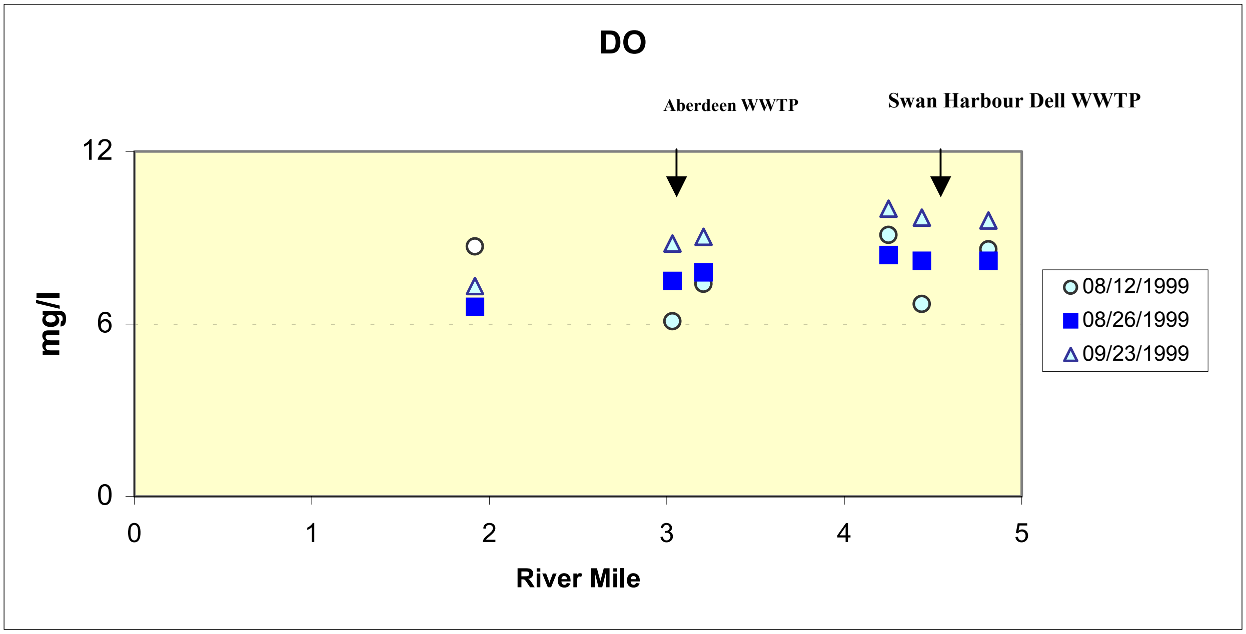
Figure A1. State Variables and Kinetic Interactions in EUTRO5

WATER QUALITY MONITORING

Maryland Department of the Environment's (MDE) Field Operations Program staff collected physical properties and chemical samples from Swan Creek on August 12, August 26 and September 23, 1999. The physical parameters - dissolved oxygen (DO), 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 0.5m from the surface. Samples were placed in plastic bottles and preserved on ice until delivered to the University of Maryland Laboratory in Solomons, MD, or the Department of Health & Mental Hygiene in Baltimore, MD for analysis. The field and laboratory protocols used to collect and process the samples are summarized in Table A1. The August and September data were used to calibrate the low flow water quality model for Swan Creek. Figures A2 – A9 present low flow water quality profiles along the creek.

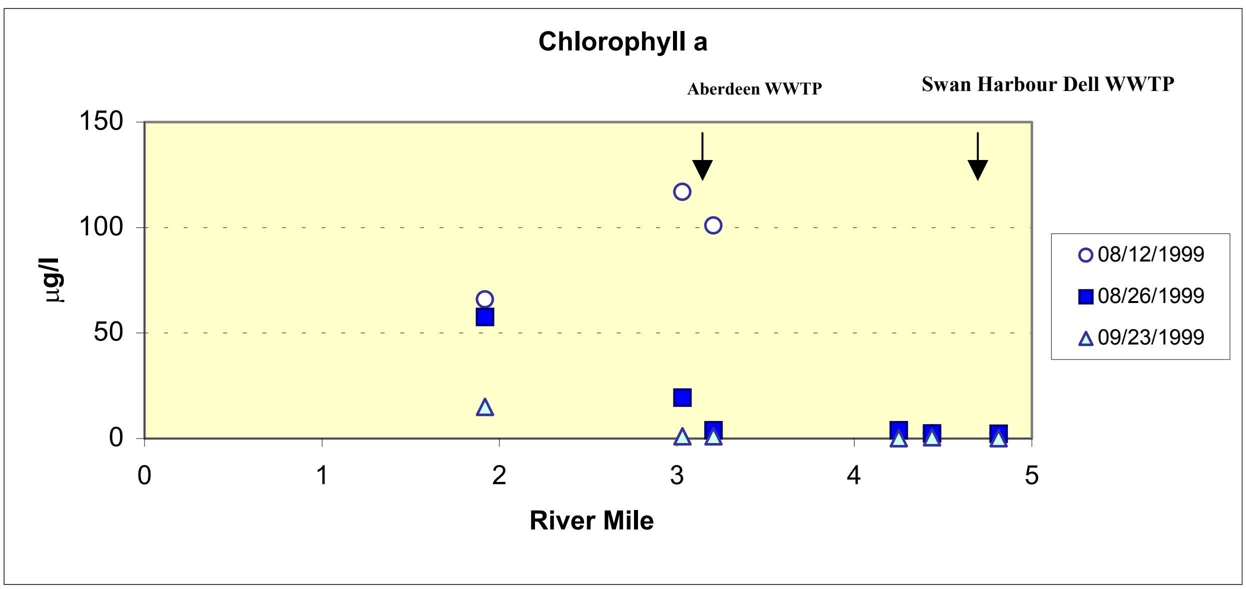
Parameter	Units	Detection Limits	*Method Reference*
IN SITU:			
Flow	cfs	0.01 cfs	Meter (Marsh-McBirney Model 2000 Flo-Mate)
Temperature	degrees Celsius	-5 deg. C to 50 deg. C	Linear thermistor network; Hydrolab Multiparameter Water Quality Monitoring Instruments Operating Manual (1995) Surveyor 3 or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

Table A1: Field and Laboratory Protocols



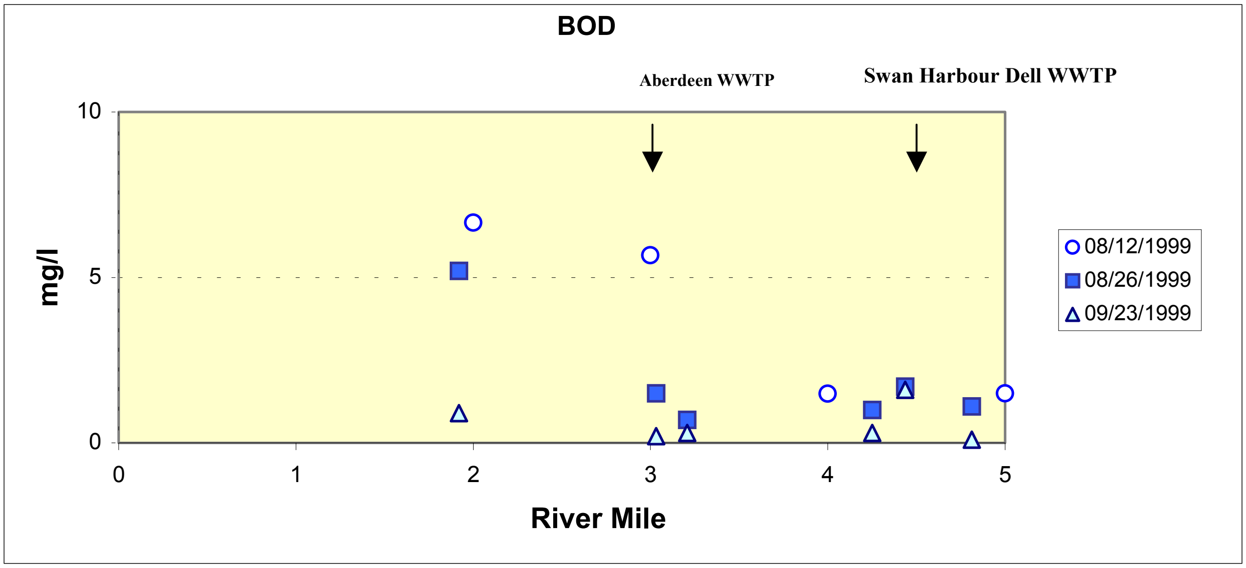
*Data collected from 09/23/99 were not used in low flow model calibration due to impact of Hurricane Floyd.

Figure A2: Longitudinal Profile of DO Data from Swan Creek Water Quality Survey



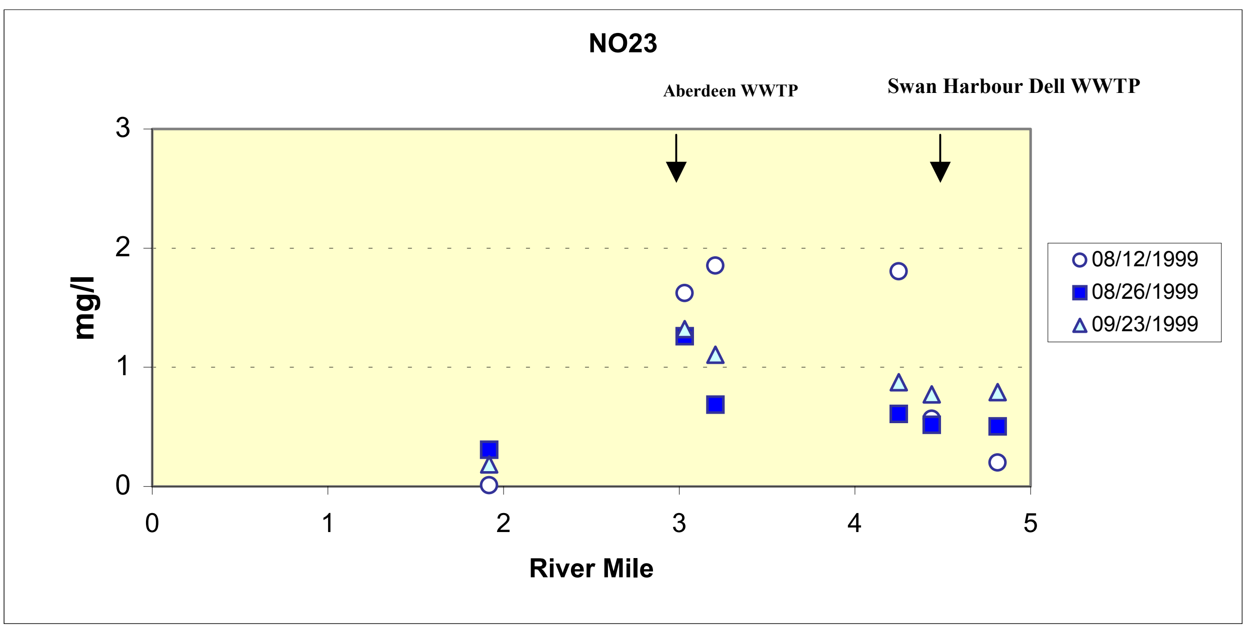
*Data collected from 09/23/99 were not used in low flow model calibration due to impact of Hurricane Floyd.

Figure A3: Longitudinal Profile of Chlorophyll a Data from Swan Creek Water Quality Survey



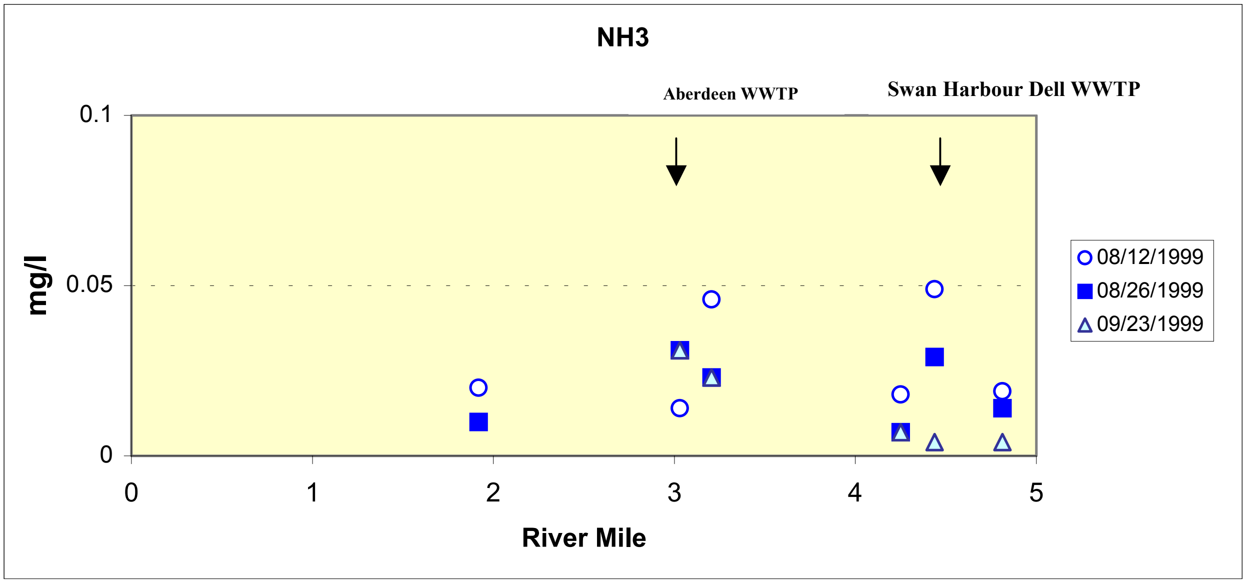
*Data collected from 09/23/99 were not used in low flow model calibration due to impact of Hurricane Floyd.

Figure A4: Longitudinal Profile of Biochemical Oxygen Demand (BOD) Data from Swan Creek Water Quality Survey



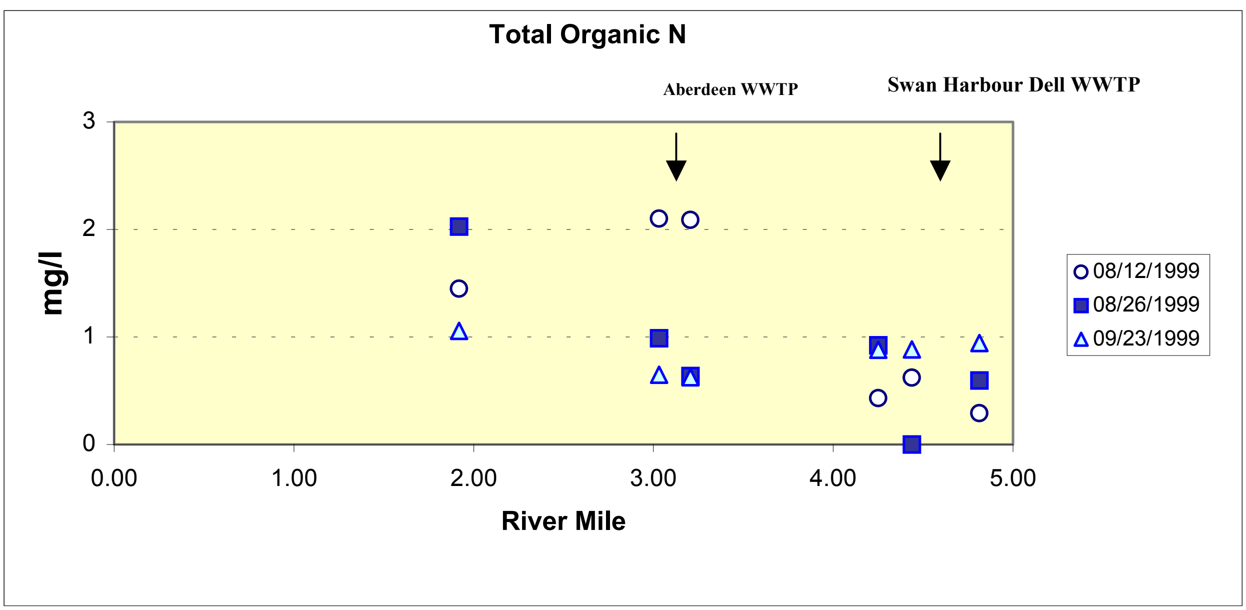
*Data collected from 09/23/99 were not used in low flow model calibration due to impact of Hurricane Floyd.

Figure A5: Longitudinal Profile of Nitrate/Nitrite (NO_{23}) Data from Swan Creek Water Quality Survey



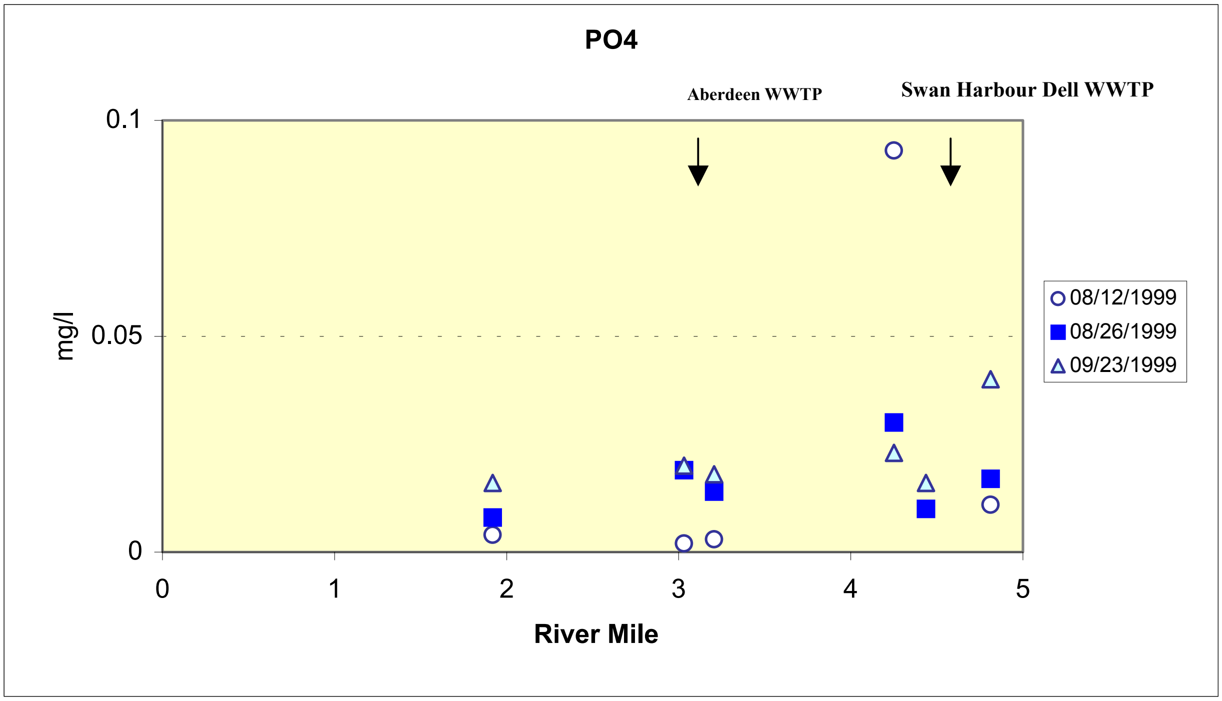
*Data collected from 09/23/99 were not used in low flow model calibration due to impact of Hurricane Floyd.

Figure A6: Longitudinal Profile of Ammonia (NH_3) Data from Swan Creek Water Quality Survey



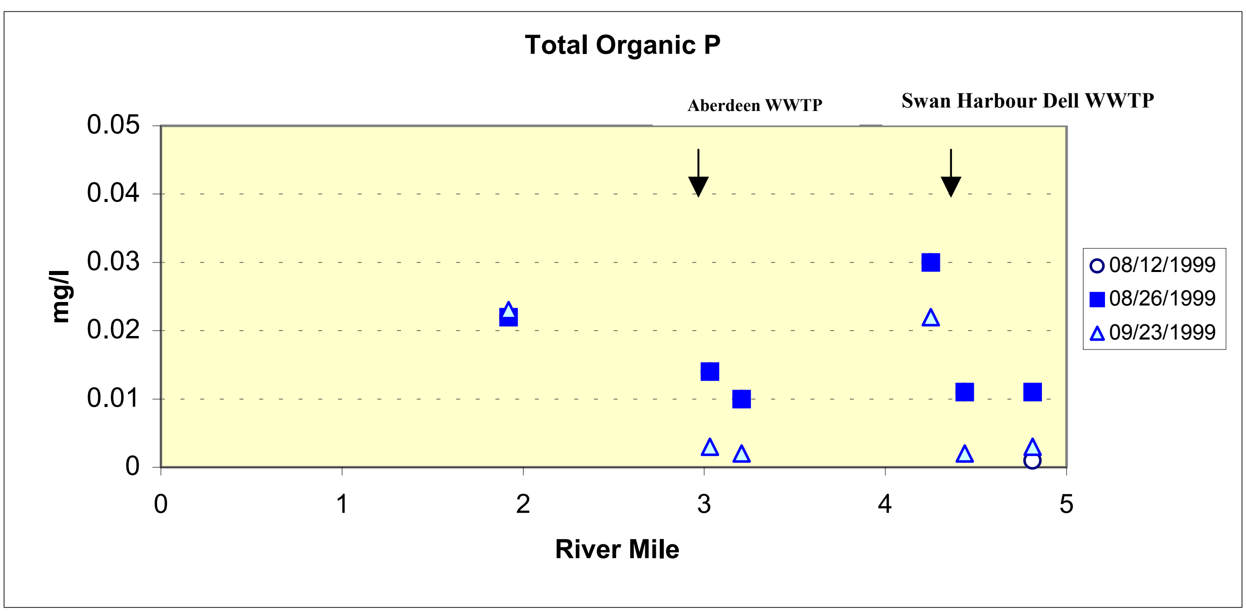
*Data collected from 09/23/99 were not used in low flow model calibration due to impact of Hurricane Floyd.

Figure A7: Longitudinal Profile of Total Organic Nitrogen Data from Swan Creek Water Quality Survey



*Data collected from 09/23/99 were not used in low flow model calibration due to impact of Hurricane Floyd.

Figure A8: Longitudinal Profile of Ortho-Phosphate (PO_4) from Swan Creek Water Quality Survey



*Data collected from 09/23/99 were not used in low flow model calibration due to impact of Hurricane Floyd.

Figure A9: Longitudinal Profile of Total Organic Phosphorus Data from Swan Creek Water Quality Survey

INPUT REQUIREMENTS [1]

Model Segmentation and Geometry

The spatial domain of the Swan Creek Eutrophication Model (SCEM) extends from the mouth of Swan Creek to approximately 5 miles up its mainstem. Following a review of the bathymetry for Swan Creek, the model was divided into 17 water quality segments. Figure A10 shows the model segmentation for the development of SCEM. Table A2 lists the volumes, characteristic lengths and interfacial areas of the 17 segments.

Seg #	Length(m)	Depth(m)	Width(m)	Cross Section (m^2)	Volume (m^3)
1	354.0	0.7	975.4	692.5	245130
2	201.5	1.0	887.0	900.3	181393
3	487.6	1.3	768.1	976.2	476059
4	332.1	1.4	902.2	1306.4	433826
5	500.9	1.4	624.8	857.3	429386
6	512.7	1.3	576.1	746.0	382496
7	520.7	2.3	432.8	989.4	515155
8	507.2	0.61	46.9	28.6	14520
9	461.1	0.61	33.5	20.5	9430
10	459.0	0.61	27.4	16.7	7679
11	646.2	0.61	22.6	13.8	8889
12	697.0	0.61	12	7.3	5101
13	291.5	0.61	12	7.3	2133
14	732.2	0.61	12	7.3	5339
15	314.3	0.61	12	7.3	2300
16	399.4	0.61	12	7.3	2923
17	375.4	0.61	12	7.3	2747

Table A2: Physical characteristic of segments used in SCEM

1 The WASP model requires all input data to be in metric units, and to be consistent with the model, all data in the Appendix will appear in metric units except the river length. Following are several conversion factors to aid in the comparison of numbers in the main document: mgd x (0.0438) = m^3s | cfs x (0.0283) = m^3s | lb / (2.2) = kg | mg/L x MGD x (8.34) / (2.2) = kg/d |

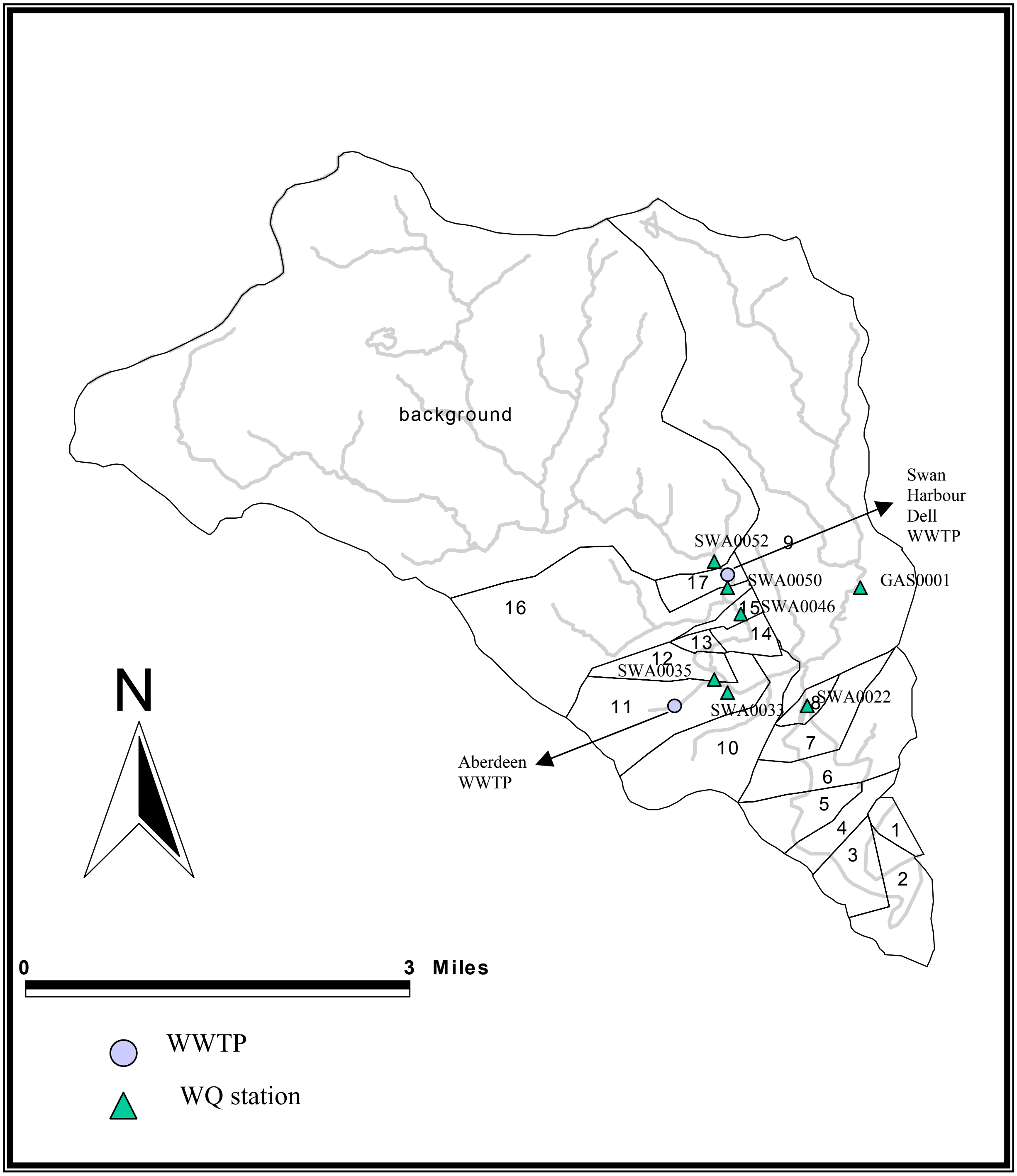


Figure A10: Model segmentation of SCEM, including subwatersheds and water quality survey stations

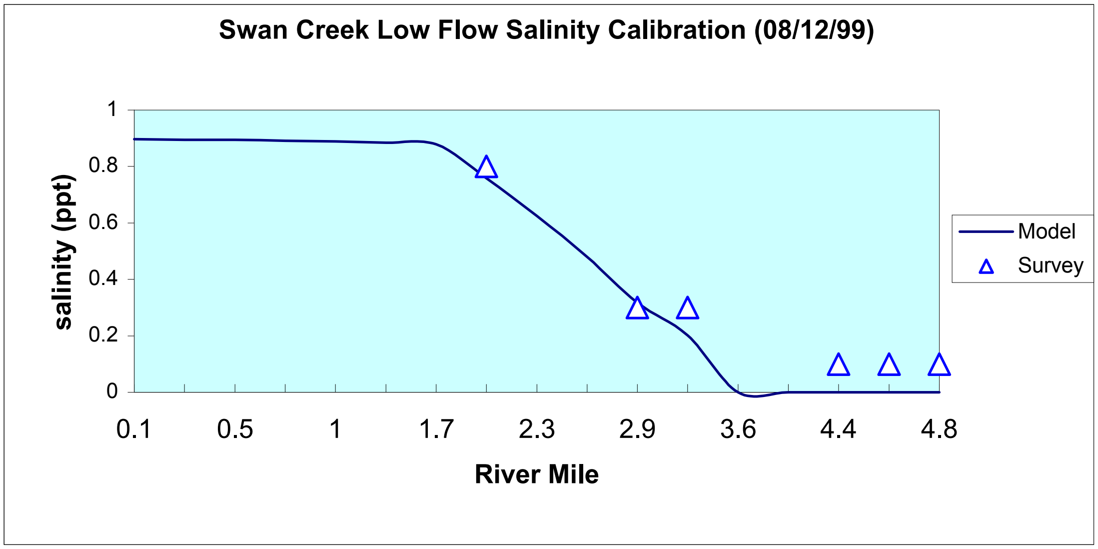
Dispersion Coefficients

The dispersion coefficients were calibrated using the WASP5.1 model and in-stream water quality data from 1999. The WASP5.1 model was set up to model salinity. Salinity is a conservative constituent meaning there are no losses due to reactions in the water. The only source in the system is the salinity from the water at the tidal boundary at the mouth. For the model execution, salinities at all boundaries except the tidal boundary were set to zero. Flows were obtained from a nearby U.S. Geological Survey (USGS) gage station as explained in more detail below. Figure A11 shows the results of the dispersion coefficients' calibration during low flow conditions (based on August 12 and August 26, 1999 Swan Creek Survey Data). Due to possible interference by Hurricane Floyd (September 16, 1999) whose rainfall compromised the low flow condition, data collected from September 23, 1999 were not used. Final values of the dispersion coefficients are listed in Table A3.

Segment	Dispersion Coefficient (m^2/sec)
1	*22*
2	*21*
3	*20*
4	*19*
5	*18*
6	*18*
7	*16*
8	*15*
9	*15*
10	*12*
11	*10*
12	*8*
13	*0.05*
	FREE FLOWING SEGMENTS
14	*0.0001*
15	*0.0001*
16	*0.0001*
17	*0.0001*

Table A3: Dispersion Coefficients used in the SCEM

(A)



(B)

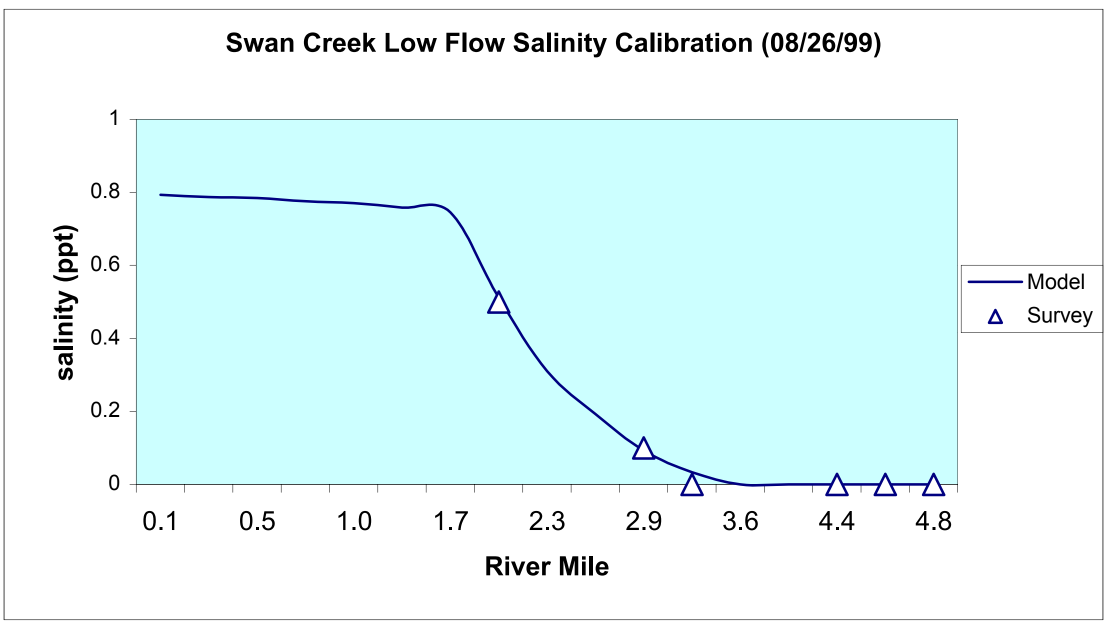


Figure A11: Salinity vs. River Mile for the calibration of low flow dispersion coefficients Using data from Swan Creek Water Quality Survey (A) August 12, 1999 (B) August 26, 1999

Freshwater Flows

Freshwater flows were calculated after the Swan Creek drainage basin was delineated into 18 subwatersheds (Figure A12). These subwatersheds were defined to assure they were consistent with the 17 water quality segments developed for the SCEM. The SCEM was calibrated for low flow condition corresponding to summer months.

The flow for each subwatershed was estimated based on three nearby USGS stations: USGS gage #01580000 (Deer Creek at Rocks, MD), USGS gage #01581700 (Winters Run near Benson, MD), USGS gage #01582000 (Little Falls at Blue Mount, MD). A low flow for each individual station was determined by obtaining an average value over the exact sampling date (August 12, August 26). A ratio of flow to drainage area was calculated for each of the USGS station and then an average of all the flow to area ratios was determined. Flow data from September 23, 1999 was not used because Hurricane Floyd passed by on September 16, 1999 and the low flow condition no longer existed. For average annual flow estimation, average annual flows measured in the past 30 years (1969-1999) from each of the three gaging stations were used. The 7Q10 and average annual flows for the individual subwatersheds were also determined in a similar manner by obtaining the 7Q10 flow for the individual USGS stations and following the above procedure. Table A4 presents flows from different subwatersheds during 7Q10 flow conditions.

	Drainage Area (sq. mile)	flow (ft^3/s)	flow (m^3/sec)
1	0.11	0.03	0.000839
2	0.45	0.12	0.003281
3	0.31	0.08	0.002278
4	0.22	0.06	0.001649
5	0.31	0.08	0.002301
6	0.71	0.19	0.005243
7	0.35	0.09	0.002597
8	0.09	0.02	0.000672
9	5.10	1.33	0.037519
10	0.80	0.21	0.005863
11	0.82	0.21	0.006047
12	0.27	0.07	0.001966
13	0.06	0.01	0.000409
14	0.14	0.04	0.000994
15	0.08	0.02	0.000620
16	1.66	0.43	0.012209
17	0.16	0.04	0.001210
Background	13.07	3.40	0.096197

Table A4: Subwatersheds flow for 7Q10 conditions

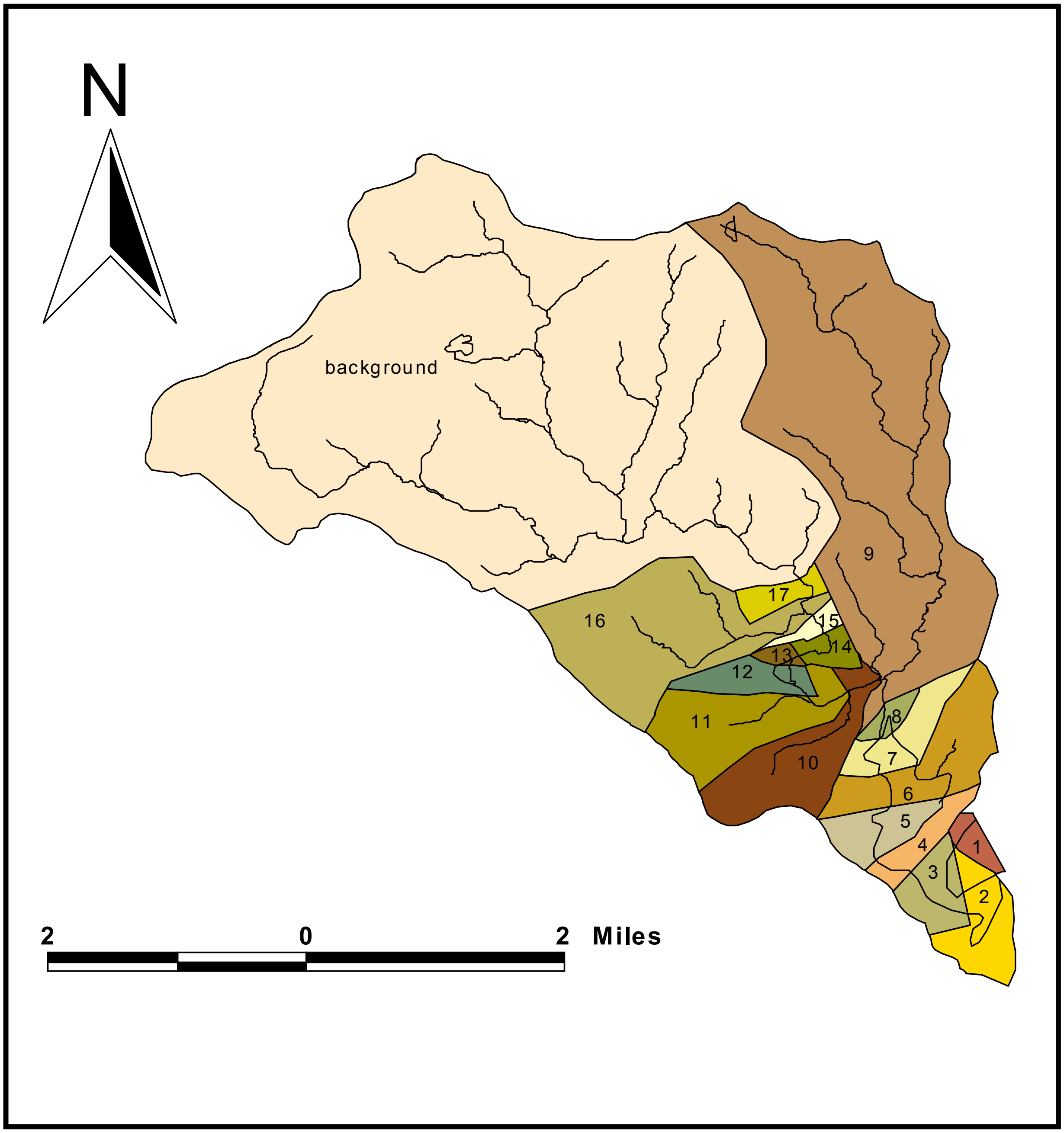


Figure A12: The 18 subwatersheds of Swan Creek Drainage Basin

Point and Nonpoint Source Loadings

There are two point sources, **Aberdeen Wastewater Treatment Plant (WWTP)** (4 MGD design capacity) and **Swan Harbour Dell WWTP** (0.05 MGD design capacity), contributing loads to Swan Creek. Nonpoint source loadings for the low flow conditions were estimated as the product of observed low flow concentrations and estimated flows as described above. Being observed loads, they account for all sources. Annual flow loads were calculated as the product of estimated average annual flow and the regional nutrient loading data provided by EPA's Chesapeake Bay Program.

Nonpoint source loads for the calibration of the model were calculated based on the observed data obtained from two water quality stations during the 1999 survey - SWA0052 and GAS0001 (please refer to Figure A10 for their locations). Because of their strategic locations, data observed from these two stations were selected to represent the background nutrient condition for the Swan Creek Watershed. Data from station SWA0052 were also used as a boundary condition for segment 17 of the SCEM. The concentrations of the nutrients, nitrogen and phosphorus, are modeled in their speciated forms. The WASP5.1 model simulates nitrogen as nitrate and nitrite (NO_{23}), ammonia (NH_3) and organic nitrogen (ON); and phosphorus as ortho-phosphate (PO_4) and organic phosphorus (OP). Nitrate and nitrite, ammonia and ortho-phosphate represent the dissolved forms of nitrogen and phosphorus. Dissolved forms of nutrients are more readily available for biological processes such as algal growth affecting chlorophyll *a* levels and dissolved oxygen concentrations. The ratios of total nutrients to dissolved nutrients used in the model scenarios were adjusted to represent values that have been measured in the field.

Environmental Conditions

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

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

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

where:

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

Different SOD values were estimated for different SCEM reaches based on observed environmental conditions and literature values (Thomann, 1987). The highest SOD values were assumed to occur in the middle segments of the river where high concentrations of nutrients and chlorophyll *a* have a high potential to settle out due to slower stream velocity.

Segment	$K_e(m^{-1})$	$T(^oC)$	SOD ($g\ O_2/m^2day$)	F-NH4 (mg NH4-N/m^2day)	F-PO4 (mg PO4-P/m^2day)
1	4.0	26	1.0	40	4
2	4.0	26	0.5	40	2
3	4.0	26	0.5	40	2
4	4.0	26	0.5	40	2
5	4.0	26	0.5	40	2
6	4.0	26	0.5	40	2
7	4.0	26	0.5	40	2
8	4.0	26	1.0	40	4
9	4.0	26	1.0	80	4
10	4.0	26	2.0	200	8
11	4.0	26	3.0	240	12
12	4.0	26	2.0	200	8
13	4.0	26	1.0	60	4
14	4.0	26	0.5	20	2
15	4.0	26	0.5	20	2
16	4.0	26	0.5	20	2
17	4.0	26	0.5	40	2

Table A5: Environmental parameters for the calibration of the model

Kinetic Coefficients

The water column kinetic coefficients are universal constants used in the SCEM 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 River (Clark and Roesh, 1978; Thomann and Fitzpatrick, 1982; Cerco, 1985), Mattawoman Creek (Panday and Haire, 1985, Panday and Haire, 1986, Domotor *et al.*, 1987), and the Patuxent River (Lung, 1993). The kinetic coefficients are listed in Table A6.

Initial Conditions

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

Constant	Code	Value
Nitrification rate	K12C	0.15 *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	0.10 *day* -1 at 20° C
temperature coefficient	K1RT	1.045
Nonpredatory phytoplankton death rate	K1D	0.010 *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	0.010 *mg* N / L
Phosphorus	KMPG1	0.001 *mg* P / P
Phytoplankton	KMPHY	0.0 *mg* C/*L*
Grazing rate on phytoplankton	K1G	0.0 *L / cell-day*
Fraction of dead phytoplankton recycled to organic		
nitrogen	FON	1.0
phosphorus	FOP	0.4
Light Formulation Switch	LGHTS	1 = Smith
Saturation light intensity for phytoplankton	IS1	300. *Ly/day*
BOD deoxygenation rate	KDC	0.10 *day* -1 at 20° C
temperature coefficient	KDT	1.05
Half saturation const. for carb. deoxygenation	KBOD	0.5
Reaeration rate constant	K2	0.5 *day* -1 at 20° C
Mineralization rate of dissolved organic nitrogen	K71C	0.02 *day* -1
temperature coefficient	K71T	1.08
Mineralization rate of dissolved organic phosphorus	K83C	0.15 *dav* -1
temperature coefficient	K83T	1.00
Phytoplankton settling velocity		0.01 m/day
Organic settling velocity		0.01 m/day

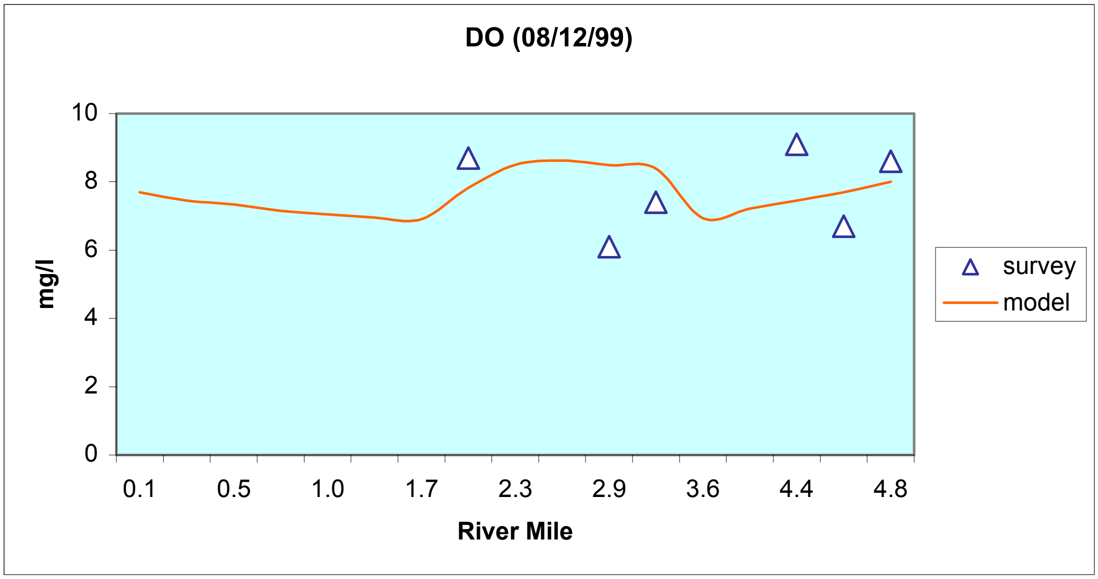
Table A6: Eutro 5 Kinetic Coefficients

CALIBRATION & SENSITIVITY ANALYSIS

The EUTRO5.1 model for low flow was calibrated through two sets of 1999 Swan Creek water quality survey data (August 12 and August 26, 1999). The nutrient loadings from the point sources for calibration purposes were calculated based on observed nutrient concentrations and actual discharge flows. The nonpoint source loadings were calculated based on projected low flow of the two sampling dates and the observed nutrient concentrations. Figures A13 – A20 show the results of the model's calibration for low flow conditions. Results from Figure A13 suggest the SCEM successfully captured the trend in the dissolved oxygen data for both calibration sets. The model predictions also coincide with the general trend of chlorophyll *a* as well as BOD values along the model segments (Figure A13-15).

Low Flow Calibration

(A)



(B)

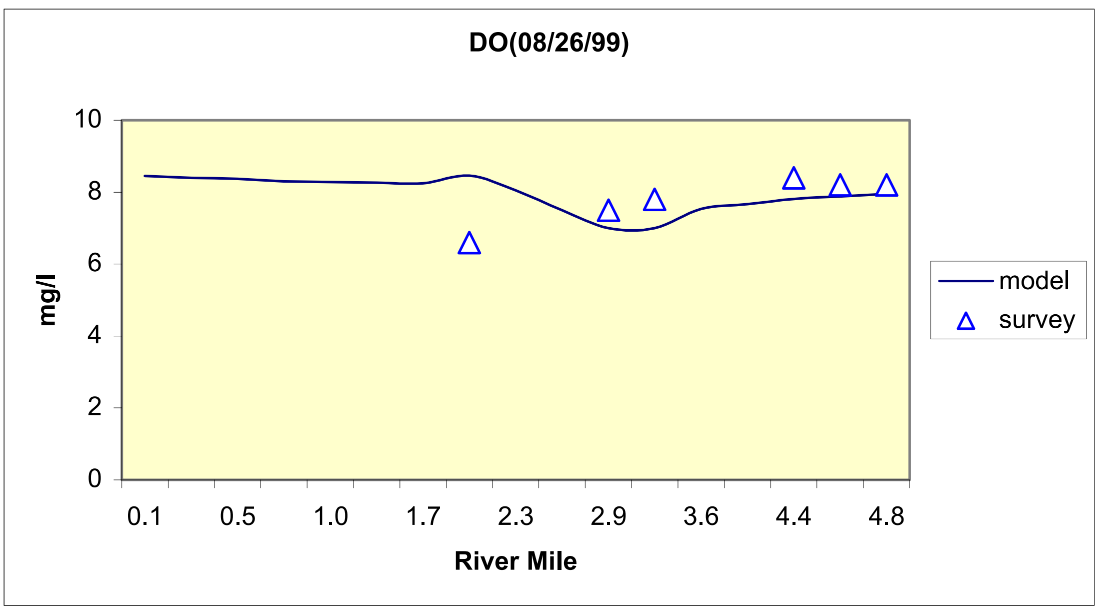
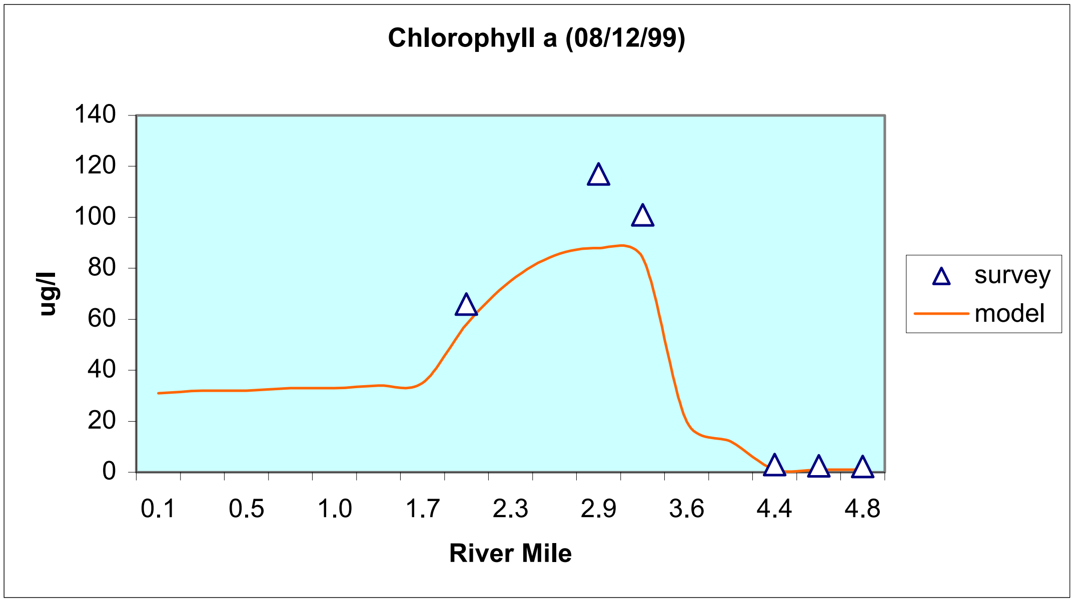


Figure A13: DO vs. River Mile for the calibration of Dissolved Oxygen for SCEM using Swan Creek survey data from (A) August 12, 1999 (B) August 26, 1999

Low Flow Calibration



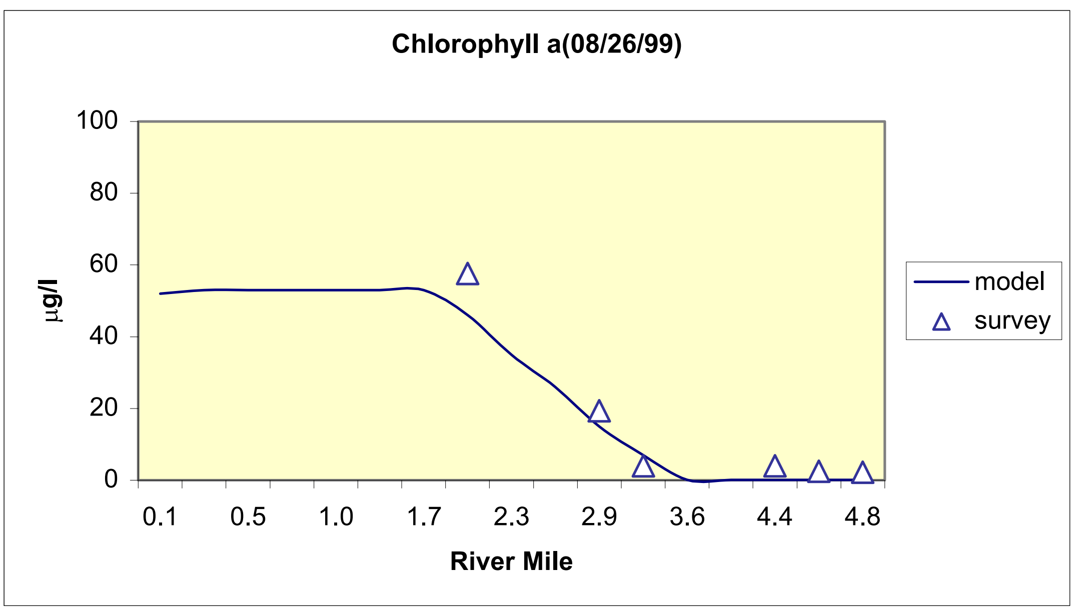
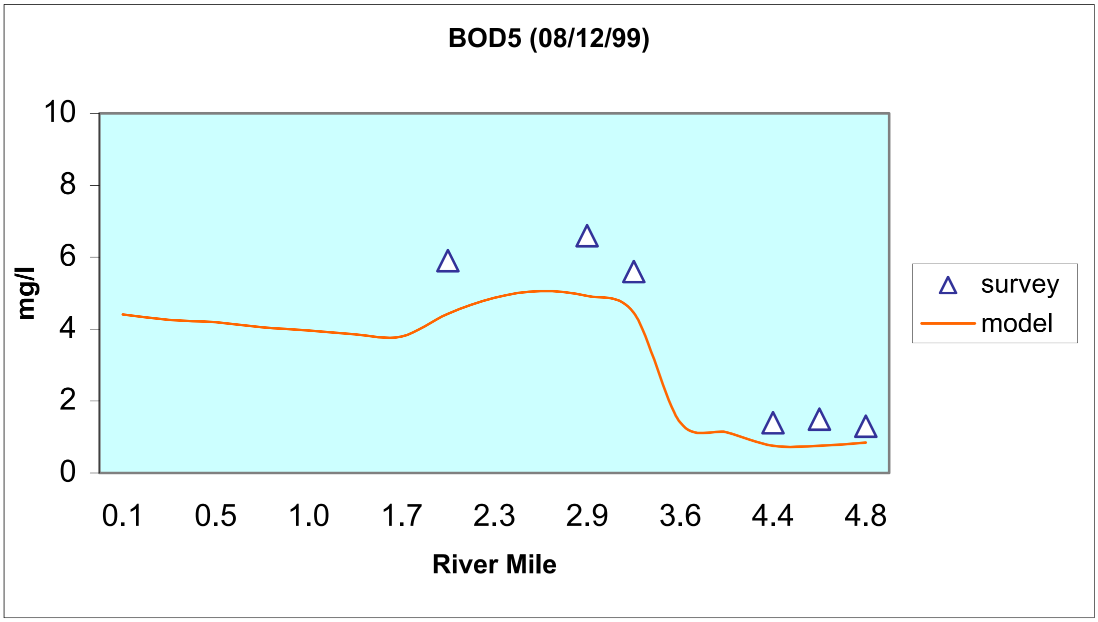


Figure A14: Chlorophyll a vs. River Mile for the calibration of Chlorophyll a for SCEM using Swan Creek survey data from (A) August 12, 1999 (B) August 26, 1999

Low Flow Calibration



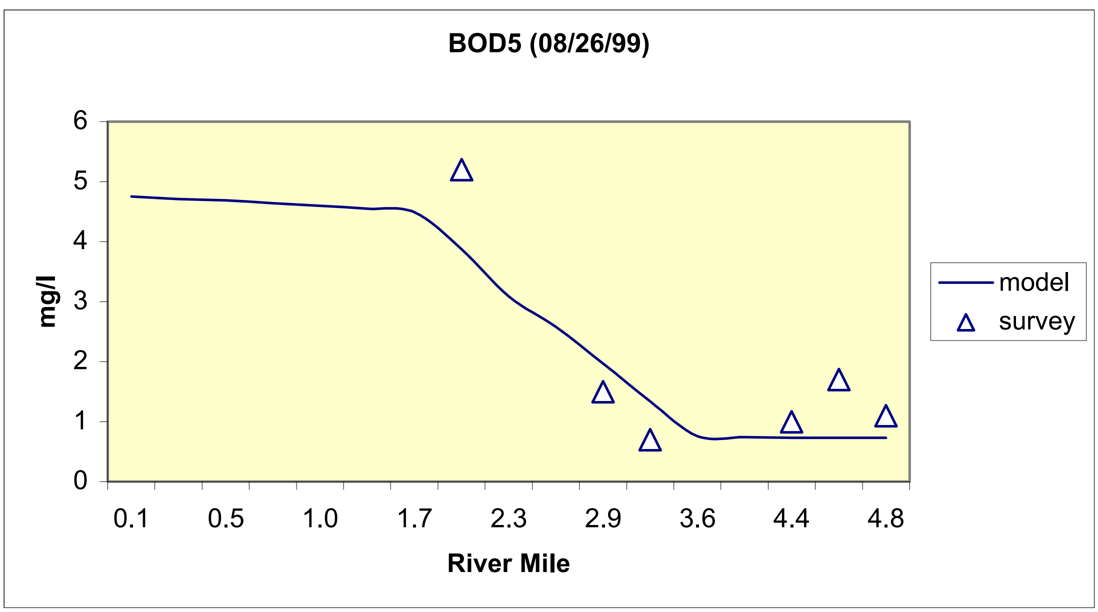
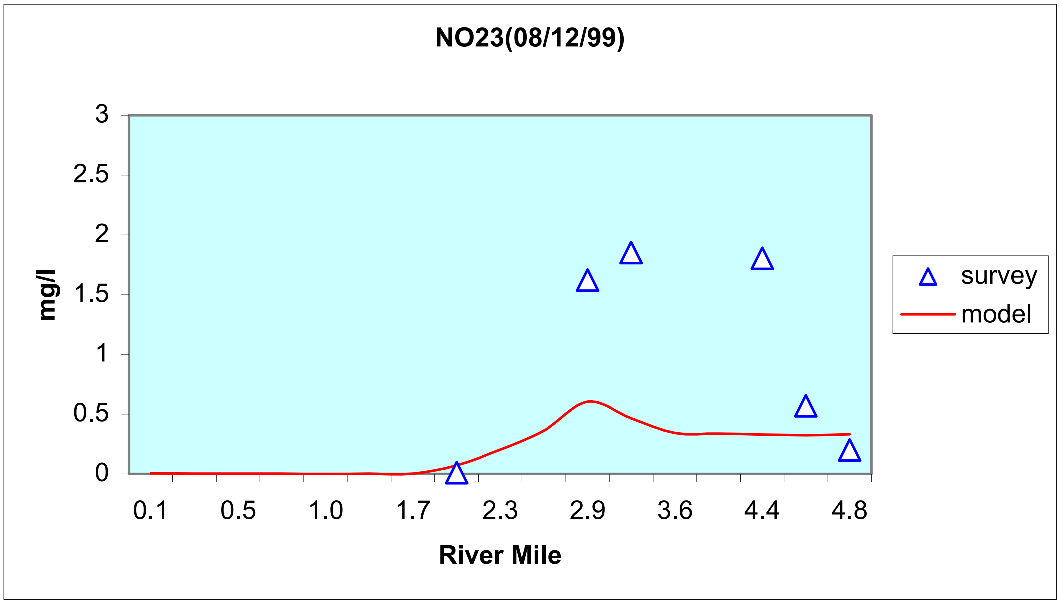


Figure A15: BOD_5 vs. River Mile for the calibration of BOD_5 for SCEM using Swan Creek survey data from (A) August 12, 1999 (B) August 26, 1999

Low Flow Calibration



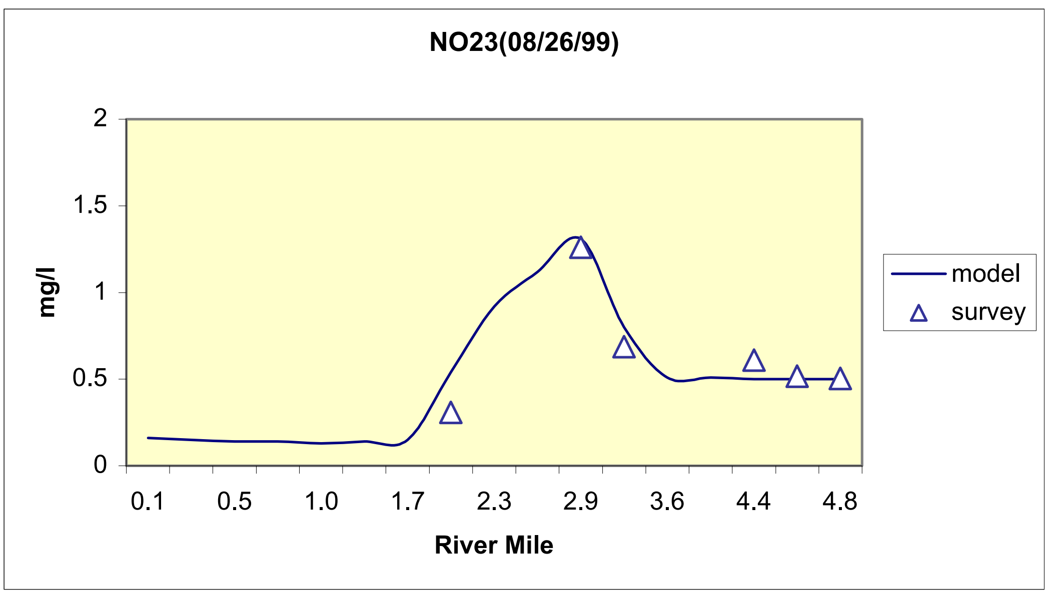


Figure A16: NO_{23} vs. River Mile for the calibration of NO_{23} for SCEM using Swan Creek survey data from (A) August 12, 1999 (B) August 26, 1999

Low Flow Calibration

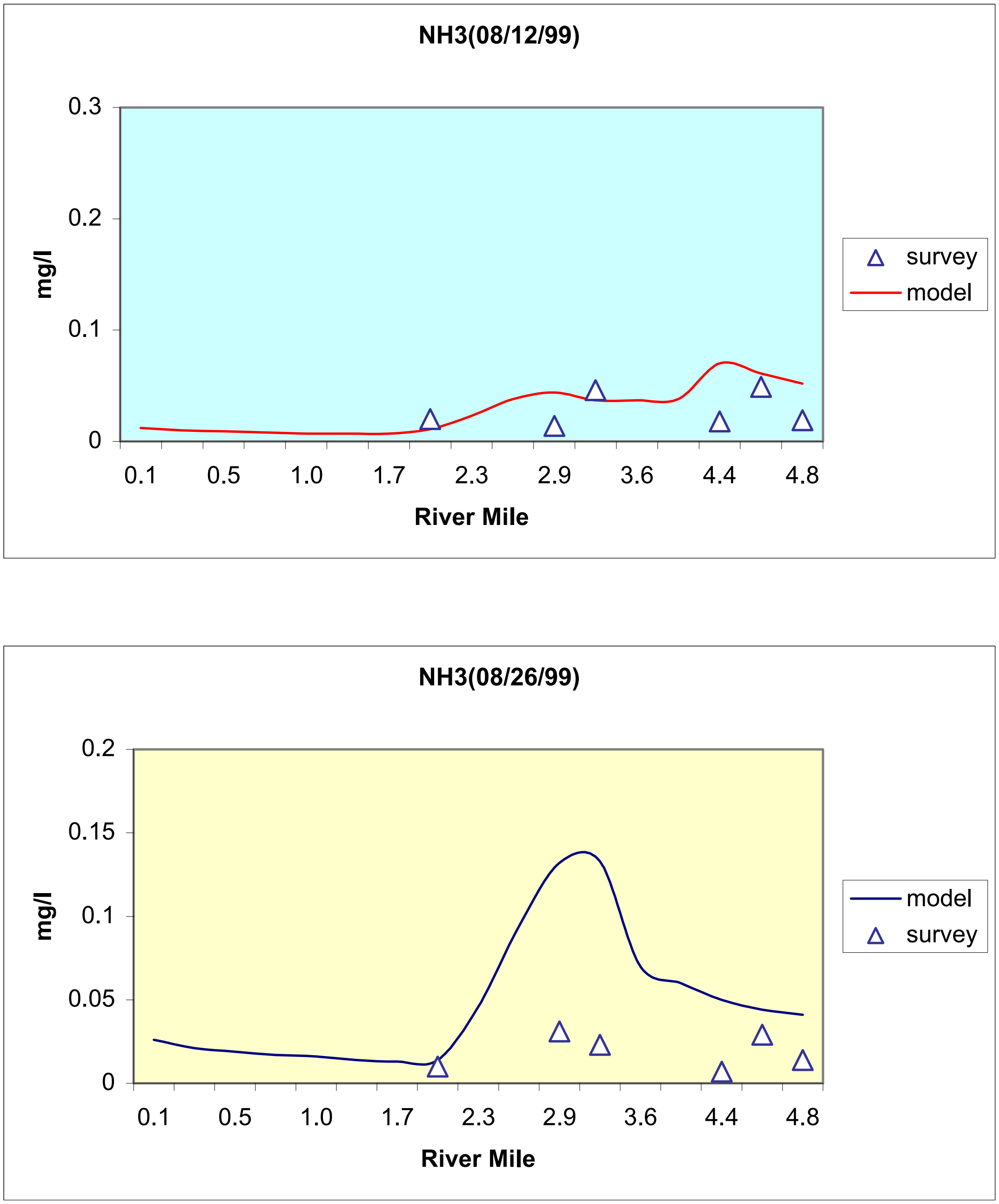


Figure A17: NH_3 vs. River Mile for the calibration of NH_3 for SCEM using Swan Creek survey data from (A) August 12, 1999 (B) August 26, 1999

Low Flow Calibration

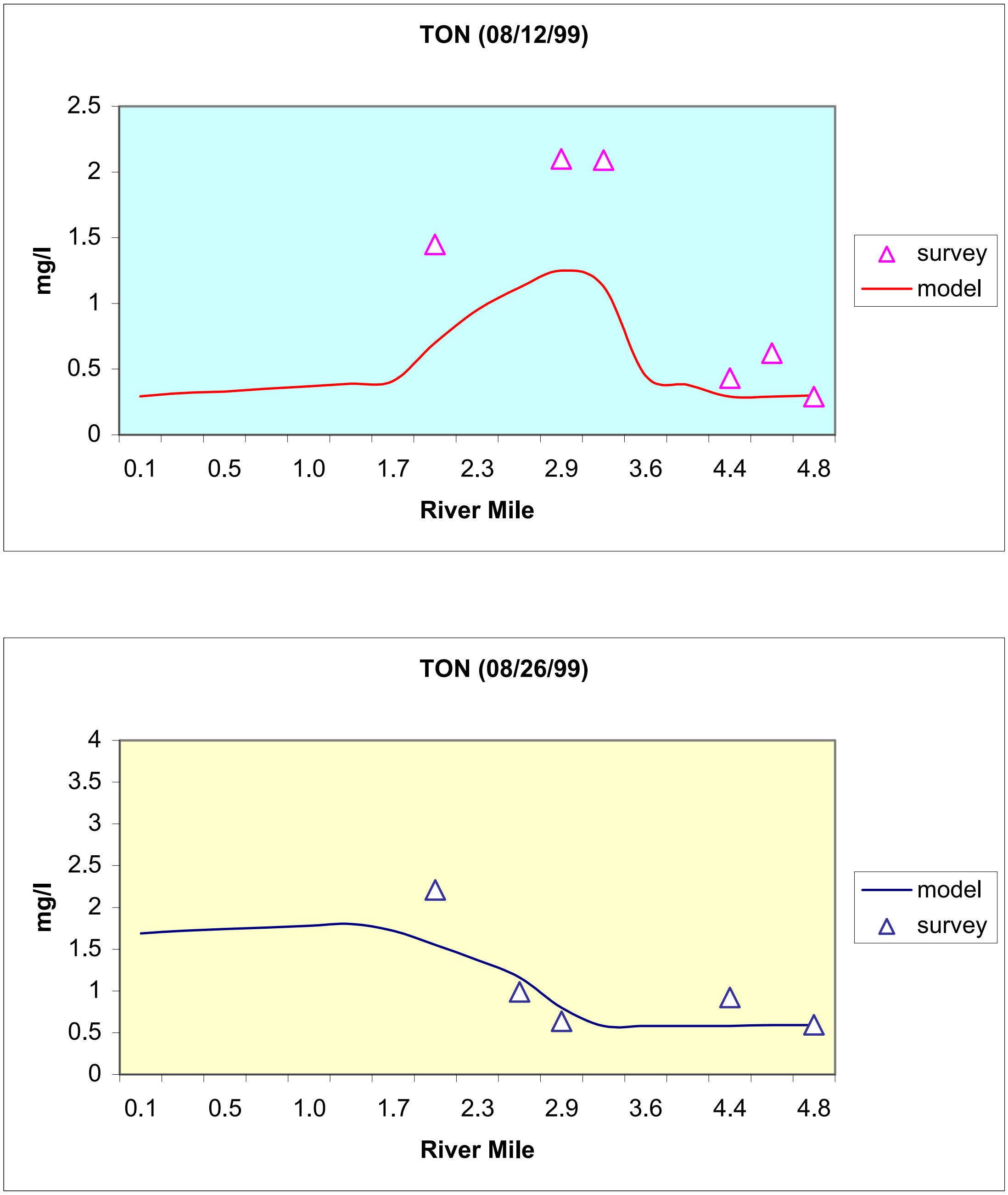
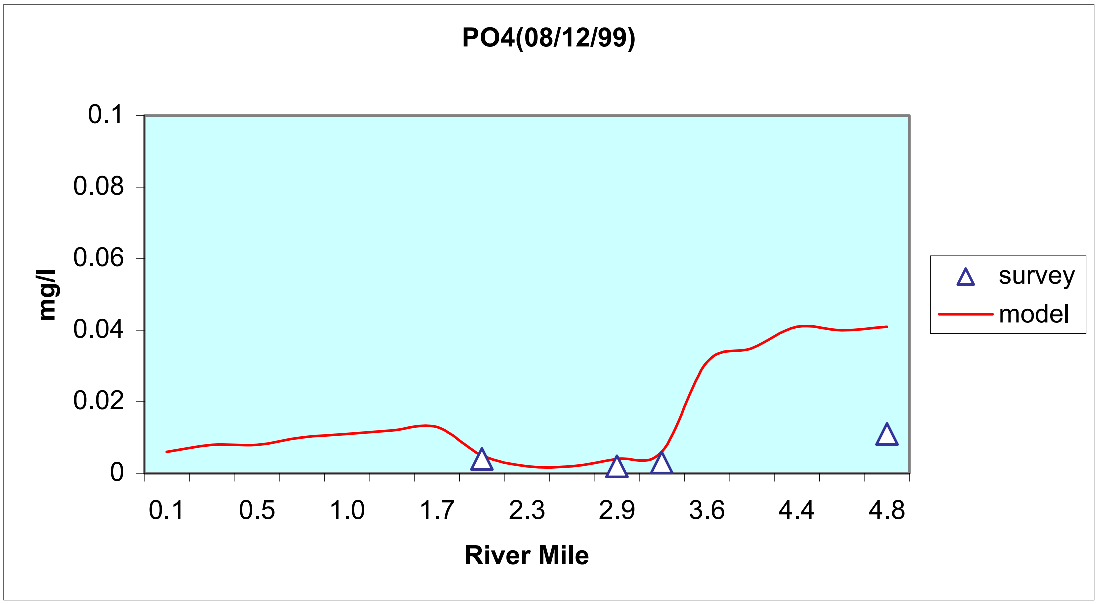


Figure A18: Total Organic Nitrogen vs. River Mile for the calibration of Total Organic Nitrogen for SCEM using Swan Creek survey data from (A) August 12, 1999 (B) August 26, 1999

Low Flow Calibration



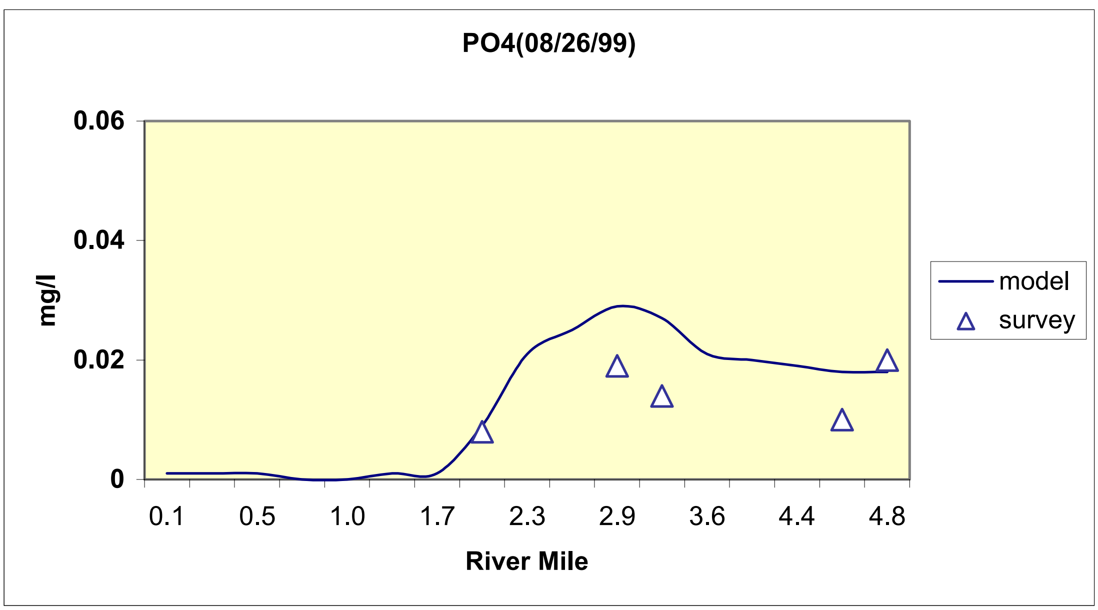
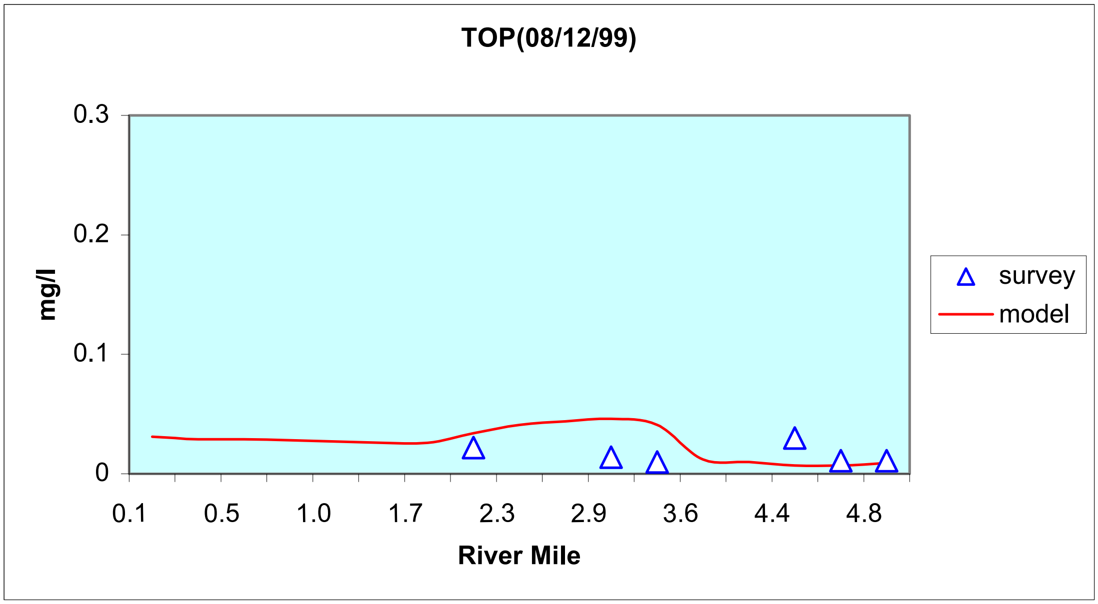


Figure A19: PO_4 vs. River Mile for the calibration of PO_4 for SCEM using Swan Creek survey data from (A) August 12, 1999 (B) August 26, 1999

Low Flow Calibration



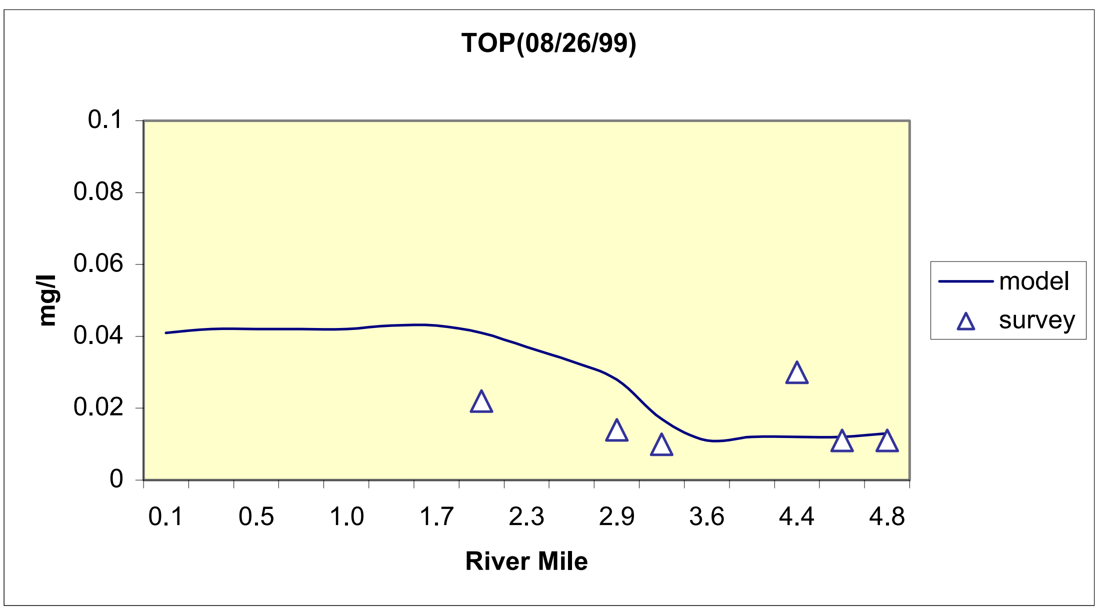


Figure A20: Total Organic Phosphorus vs. River Mile for the calibration of Total Organic Phosphorus for SCEM using Swan Creek survey data from (A) August 12, 1999 (B) August 26, 1999

SYSTEM RESPONSE

The EUTRO5.1 model of Swan Creek was run through various iterated loading scenarios during low flow and average annual flow conditions to project the impacts of nutrients on algal production (as chlorophyll *a*) and low dissolved oxygen in the stream. The responses of various scenarios from the SCEM were analyzed to determine the TMDLs of nitrogen and phosphorus for Swan Creek during low and average annual flow conditions.

Model Run Descriptions

Baseline Conditions(Low Flow)

The baseline condition represents the expected conditions of the stream under current loading conditions during critical low flow (7Q10 flow condition). The 7Q10 low flow for each subwatershed was estimated using the same method described above to estimate low flow using four nearby USGS gages. All the environmental parameters used for the baseline condition remained the same for the low flow calibration of the model. The total nonpoint source loads were computed as the product of observed nutrient concentrations during the 1999 survey and the estimated 7Q10 low flow. The nonpoint source loads for SCEM can be seen in Table A8. Because the loads are based on observed concentrations, they account for all "natural" and human-induced sources. The loads from both point sources are included as part of the load entering segments 11 and 17. The point source loads reflect their approved water and sewer plan maximum flows as well as current NPDES permit nutrient limits (see Table A7).

Parameter*	Aberdeen WWTP	Swan Harbour Dell WWTP	UNIT
Flow	4	0.05	MGD
NH_3	0.06	0.05	mg/L
NO_{23}	6.63	23.3	mg/L
PO_4	0.09	4.8	mg/L
Chlorophyll a	0.33	0.16	μg/L
CBOD	30	45	mg/L
DO	5	5	mg/L
TON	3.32	1.28	mg/L
TOP	0.56	1.4	mg/L

*The concentrations of total nitrogen and phosphorus species are estimated based on NPDES permit limits. The ratios between different species are adjusted according to observed effluent data.

Table A7: Point sources' concentrations used in the SCEM.

A. BASELINE (LOW FLOW)[1]

Segment Nos.	NH4 mg/l	NO_{23} mg/l	PO_4 mg/l	CHLa µg/l	CBOD mg/l	O_2 mg/l	ON mg/l	OP mg/l	Flow m^3/s
9	0.02	0.68	0.04	1.31	1.69	7.3	0.69	0.02	0.038
10	0.02	0.68	0.04	1.31	1.69	7.3	0.69	0.02	0.006
11	0.02	0.68	0.04	1.31	1.69	7.3	0.69	0.02	0.006
16	0.02	0.68	0.04	1.31	1.69	7.3	0.69	0.02	0.012
17	0.02	0.68	0.04	1.31	1.69	7.3	0.69	0.02	0.096

B. TMDL (LOW FLOW)[1]

Segment Nos.	NH4 mg/l	NO_{23} mg/l	PO_4 mg/l	CHLa µg/l	CBOD mg/l	O_2 mg/l	ON mg/l	OP mg/l	Flow m^3/s
9	0.012	0.41	0.024	1.31	1.69	7.3	0.41	0.012	0.038
10	0.012	0.41	0.024	1.31	1.69	7.3	0.41	0.012	0.006
11	0.012	0.41	0.024	1.31	1.69	7.3	0.41	0.012	0.006
16	0.012	0.41	0.024	1.31	1.69	7.3	0.41	0.012	0.012
17	0.012	0.41	0.024	1.31	1.69	7.3	0.41	0.012	0.096

C. BASELINE (AVERAGE ANNUAL FLOW)[2]

Segment Nos.	NH4 mg/l	NO_{23} mg/l	PO_4 mg/l	CHLa µg/l	CBOD mg/l	O_2 mg/l	ON mg/l	OP mg/l	Flow m^3/s
9	0.11	1.11	0.09	1.31	1.69	7.3	1.97	0.13	0.209
10	0.18	1.56	0.22	1.31	1.69	7.3	2.35	0.29	0.033
11	0.17	1.47	0.21	1.31	1.69	7.3	2.20	0.26	0.034
16	0.14	1.30	0.17	1.31	1.69	7.3	2.05	0.22	0.068
17	0.11	1.14	0.10	1.31	1.69	7.3	2.01	0.15	0.536

D. TMDL (AVERAGE ANNUAL FLOW)[3]

Segment Nos.	NH4 mg/l	NO_{23} mg/l	PO_4 mg/l	CHLa µg/l	CBOD mg/l	O_2 mg/l	ON mg/l	OP mg/l	Flow m^3/s
9	0.07	0.67	0.05	1.31	1.69	7.3	1.18	0.08	0.209
10	0.11	0.94	0.13	1.31	1.69	7.3	1.41	0.17	0.033
11	0.10	0.88	0.12	1.31	1.69	7.3	1.32	0.16	0.034
16	0.08	0.78	0.10	1.31	1.69	7.3	1.23	0.13	0.068
17	0.07	0.69	0.06	1.31	1.69	7.3	1.21	0.09	0.536

1. The loading concentrations were calculated based upon the average observed values (08/12/99 and 08/26/99) from WQ station SWA0052 and GAS0001
2. Based on 10 years average regional watershed nutrient loading data (EPA Chesapeake Bay Program, 2000)
3. Based on 40% reduction of 10 years average regional watershed nutrient loading data (EPA Chesapeake Bay Program, 2000)

Table A8: Nonpoint source concentrations used in various scenarios in SCEM

Future TMDL (Low Flow):

The future TMDL scenario represents the improved conditions associated with the maximum allowable loads to the stream during critical low flow period. The flow rate in this scenario was identical to the baseline condition. All the environmental parameters (except for nutrient fluxes and sediment oxygen demand) and kinetic coefficients used in the model remained the same as the baseline condition. The nitrogen and phosphorus loads were reduced from the baseline condition to meet the chlorophyll *a* target threshold of 50 $\mu g/L$, and the dissolved oxygen criterion of no less than 5.0 mg/L. To address the algal blooms and dissolved oxygen deficiency, the TMDL scenario also proposed a 40 % reduction of both nitrogen and phosphorus input from nonpoint sources (NPS). This scenario also accounts for a margin of safety computed as 5% of the NPS loading. The nutrient fluxes (including NH_4 and PO_4) and sediment oxygen demand in the model were estimated based on the percent reduction of organic matter settling to the bottom. The loads from the WWTP are included as part of the load entering segment 11 (Aberdeen WWTP) and segment 17 (Swan Harbour Dell WWTP). These point source loads reflect approved water and sewer plan maximum flows and current NPDES permit nutrient limits. More information about the point source loads can be found in the Technical Memorandum entitled, *"Significant Nutrient Point Sources in Swan Creek Watershed"*.

Average Annual Flow Baseline:

The baseline condition represents the expected conditions of the stream under current loading conditions during average annual flow condition. The average annual flow for each sub-watershed was estimated using the same method described above to estimate low flow using four nearby USGS gages. All the environmental parameters used for baseline condition remained the same as those used for model calibration. The nonpoint source loads were estimated from the product of projected average annual flow and the regional watershed nutrient loading data provided by EPA's Chesapeake Bay Program (2000). The loads from both point sources are included as part of the load entering segment 11 and 17. The point source loads reflect their approved water and sewer plan maximum flows as well as current NPDES permit nutrient limits.

Future TMDL (Average Annual Flow):

The baseline condition represents the expected conditions of the stream under current loading conditions during average annual flow condition. The average annual flow for each sub-watershed was estimated using the same method described above to estimate low flow using four nearby USGS gages. All the environmental parameters used for baseline condition remained the same as the ones used for model calibration. The nonpoint source loads were estimated from the product of projected average annual flow and the 60% of the regional watershed nutrient loading data provided by EPA's Chesapeake Bay Program (2000). The nutrient fluxes (including NH_4 and PO_4) and sediment oxygen demand in the model were also estimated based on the percent reduction of organic matter settling to the bottom. The loads from both point sources are included as part of the load entering segment 11 and 17. The point source loads reflect their approved water and sewer plan maximum flows as well as current NPDES permit nutrient limits.

Scenario Results

<u>Baseline Condition(Low Flow Condition) :</u>

This scenario simulates critical low stream flow (7Q10) conditions during the summer season. Water quality parameters (e.g., nutrient concentrations) are based on 1999 observed data. Point source loads assume maximum approved water and sewer plan flows and NPDES permit limits expected in the effluent (4.0 MGD at **Aberdeen WWTP**, 0.05 MGD at **Swan Harbour Dell** WWTP). Results for this scenario, representing the base-line condition for summer low flow, are summarized in Figures A21 to A28. The dissolved oxygen level in the middle segment of the stream has a potential to be below the standard (5.0 mg/L) (Figure A21). The peak chlorophyll *a* level is above 50 µg/L under the critical condition of temperature and flows to the lower segments at the mouth of the river (Figure A22).

<u>TMDL (Low Flow Condition):</u>

The TMDL simulates the future condition of maximum allowable loads for critical low stream flow (7Q10) conditions during summer season to meet water quality standards in Swan Creek. Results for the TMDL are illustrated in comparison to the appropriate baseline condition (solid line) in Figures A29-A36. Under the nutrient load reduction conditions described above for this scenario, the model results indicate the minimum concentrations of dissolved oxygen along the length of the river are above the water quality criterion of 5.0 mg/L (Figure A27). The model results show that chlorophyll *a* concentrations are below the levels of 50 µg/L over the entire length of Swan Creek (Figure A30).

Baseline Condition

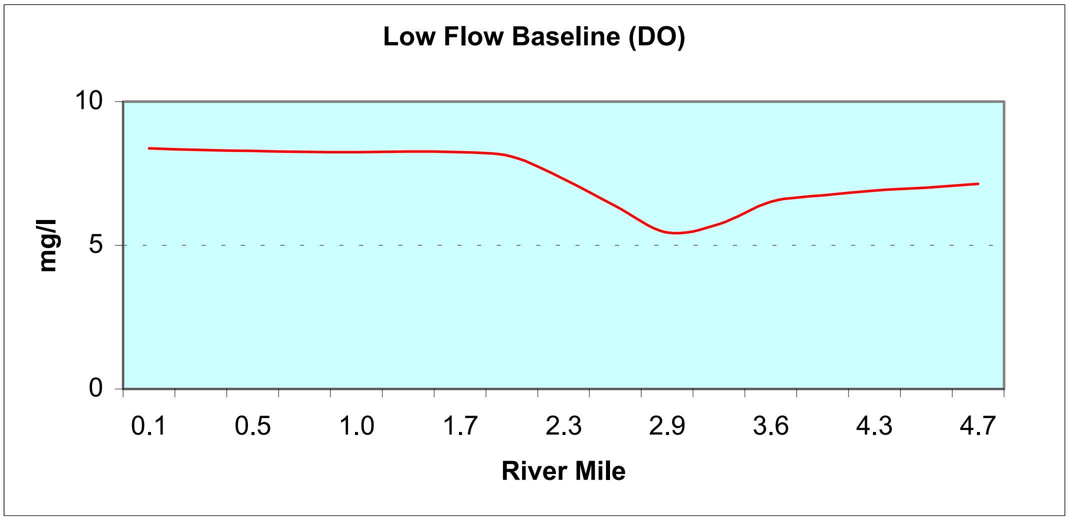


Figure A21: DO vs. River Mile for SCEM Baseline Condition

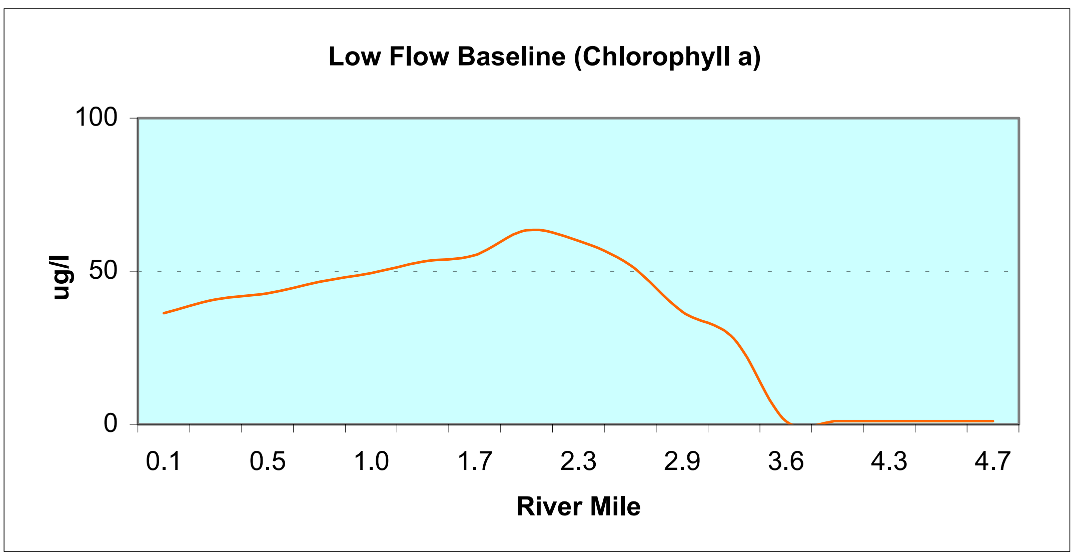


Figure A22: Chlorophyll a vs. River Mile for SCEM Baseline Condition

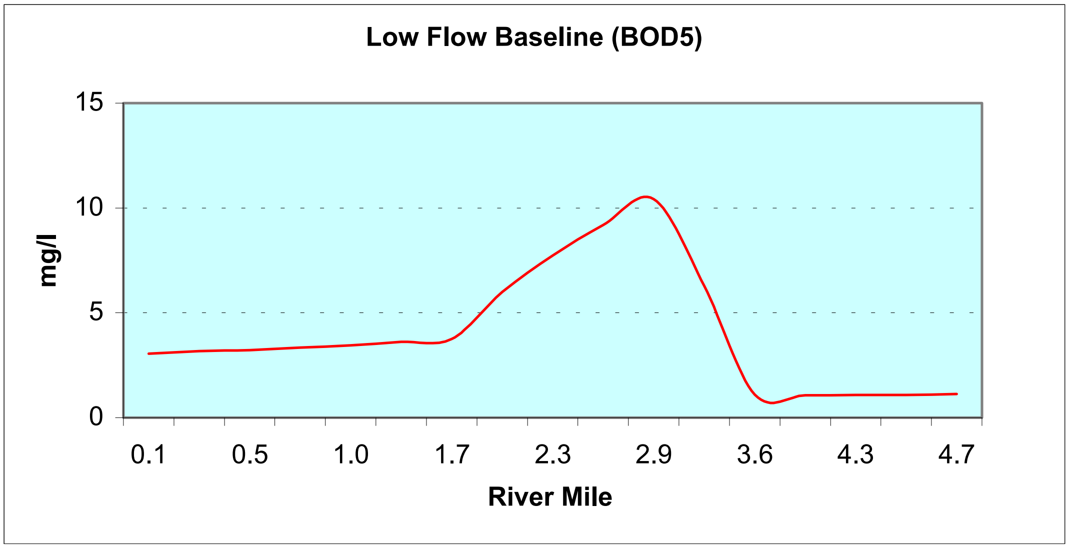


Figure A23: BOD vs. River Mile for SCEM Baseline Condition

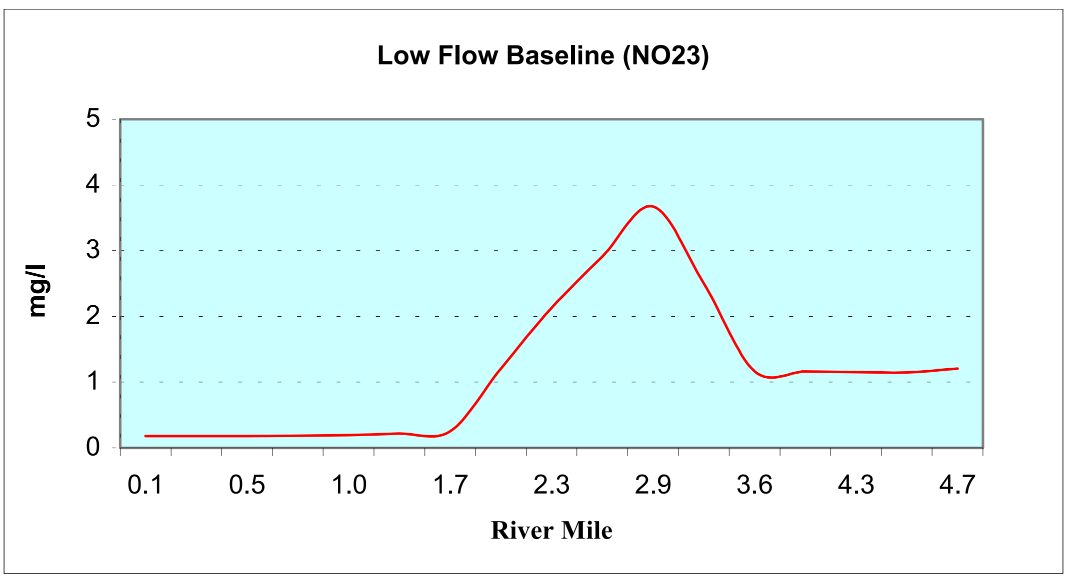


Figure A24: NO_{23} vs. River Mile for SCEM Baseline Condition

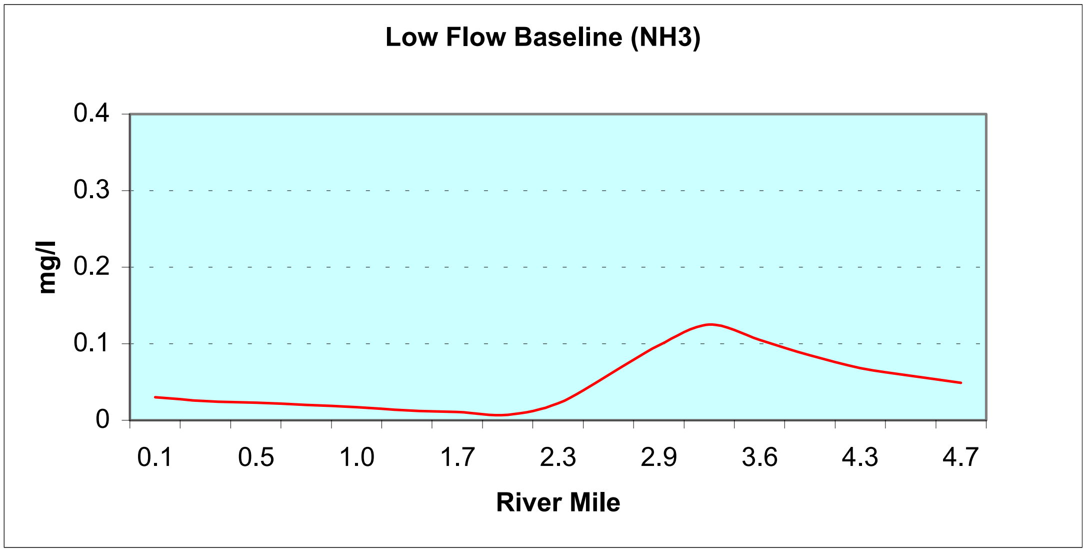


Figure A25: NH_3 vs. River Mile for SCEM Baseline Condition

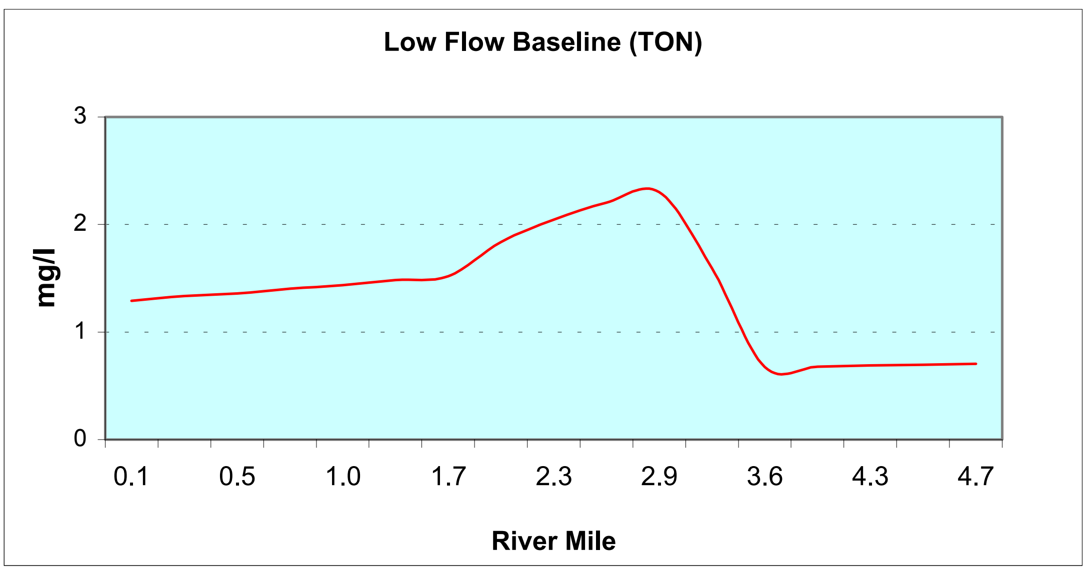


Figure A26: Total Organic Nitrogen vs. River Mile for SCEM Baseline Condition

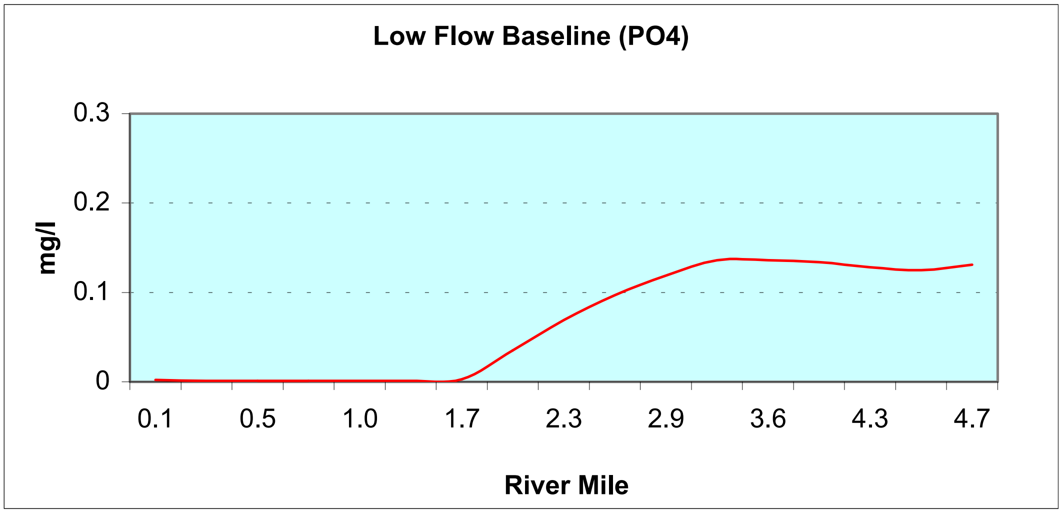


Figure A27: PO_4 vs. River Mile for SCEM Baseline Condition

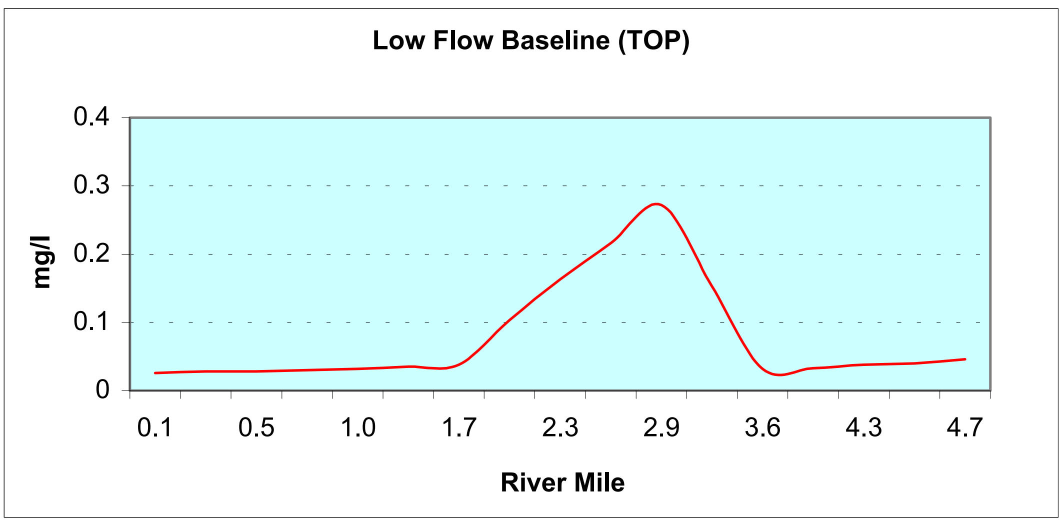


Figure A28: Total Organic Phosphorus vs. River Mile for SCEM Baseline Condition

Future TMDL

——————— **Baseline** - - - - - - - - - **TMDL**

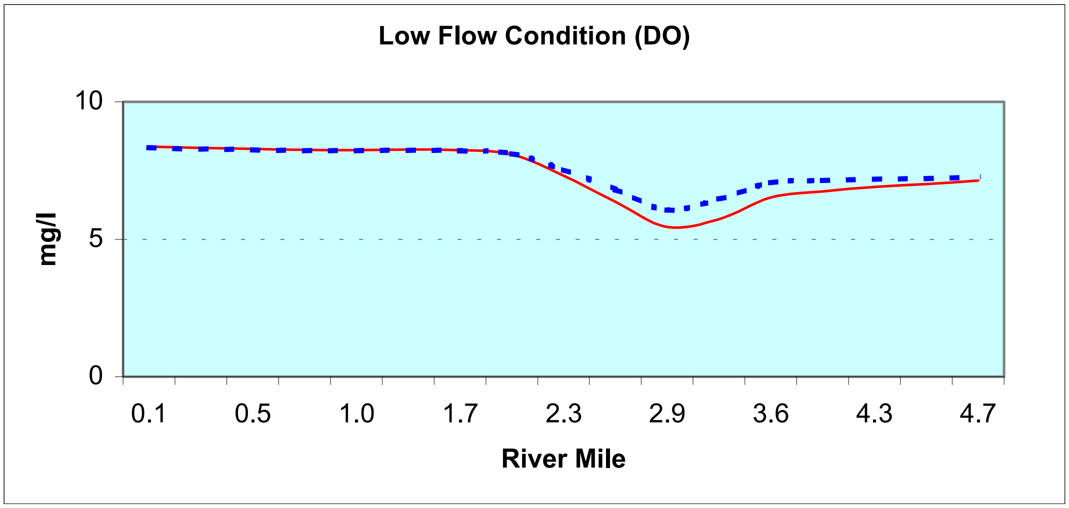


Figure A29: DO vs. River Mile for SCEM TMDL (dash line)

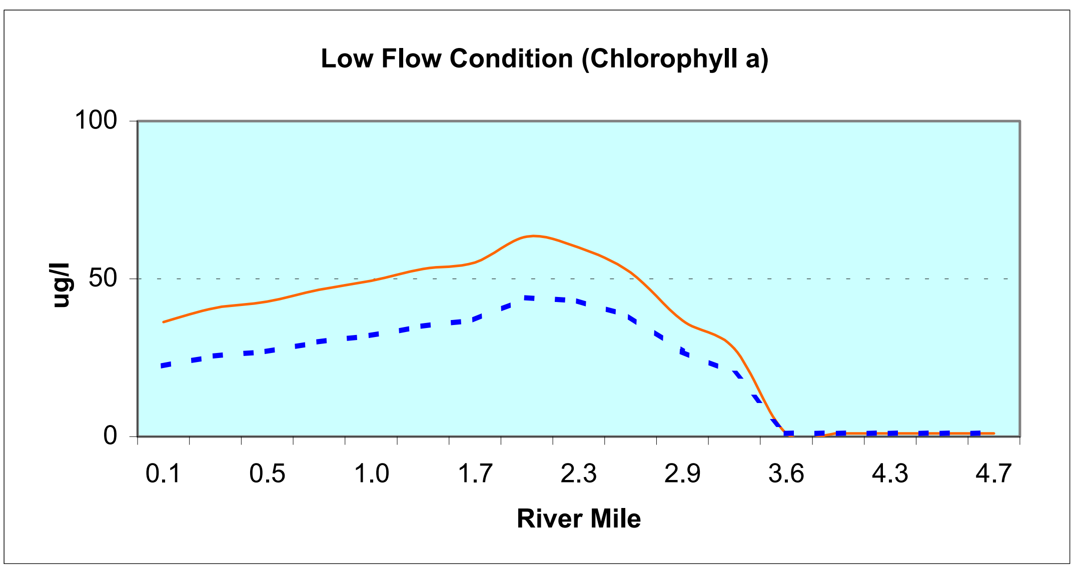


Figure A30: Chlorophyll a vs. River Mile for SCEM TMDL (dash line)

Future TMDL

——————— **Baseline** - - - - - - - - - **TMDL**

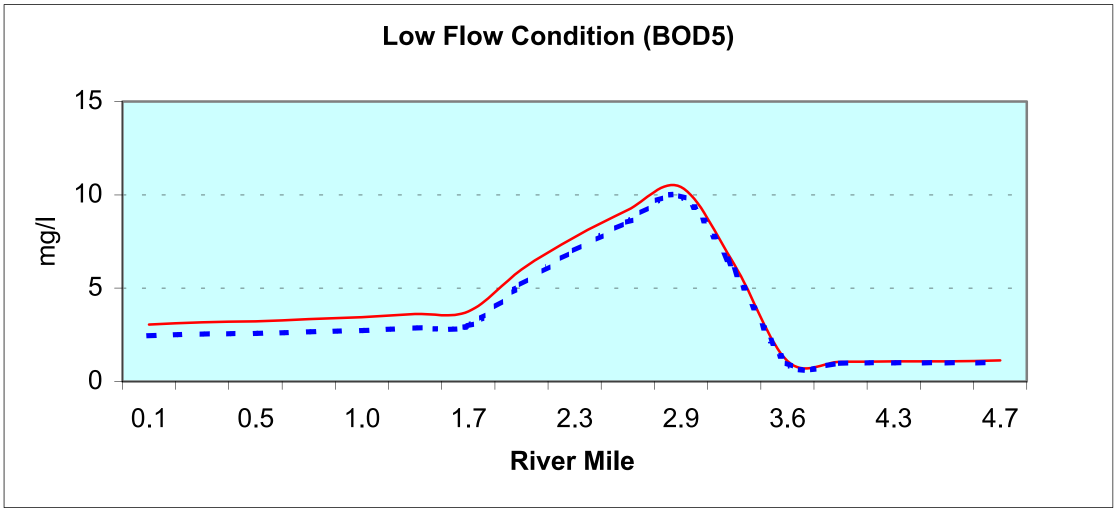


Figure A31: BOD vs. River Mile for SCEM TMDL (dash line)

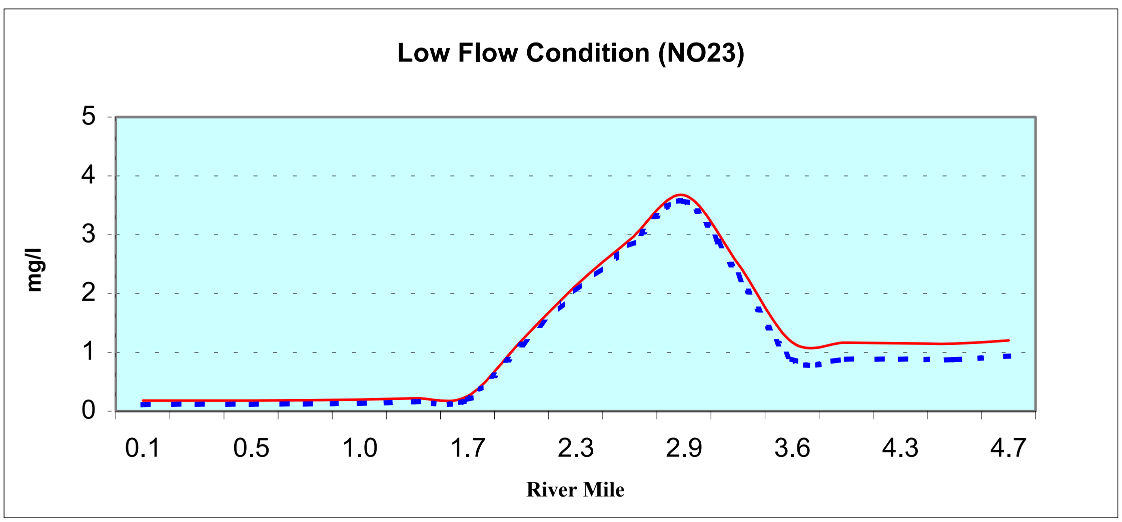


Figure A32: NO_{23} vs. River Mile for SCEM Future Scenario A (dash line)

Future TMDL

——————— **Baseline** - - - - - - - - - **TMDL**

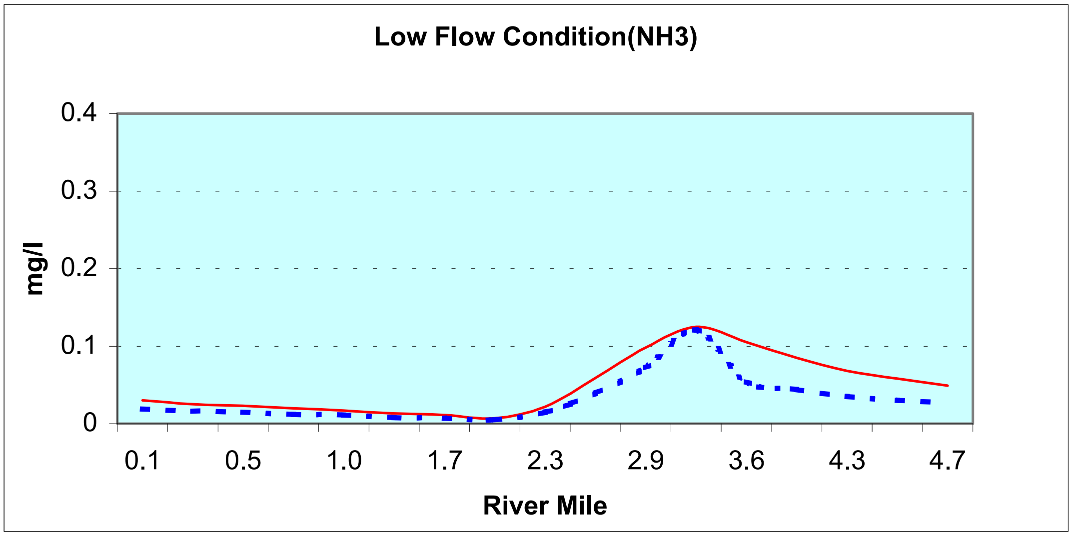


Figure A33: NH_3 vs. River Mile for SCEM TMDL (dash line)

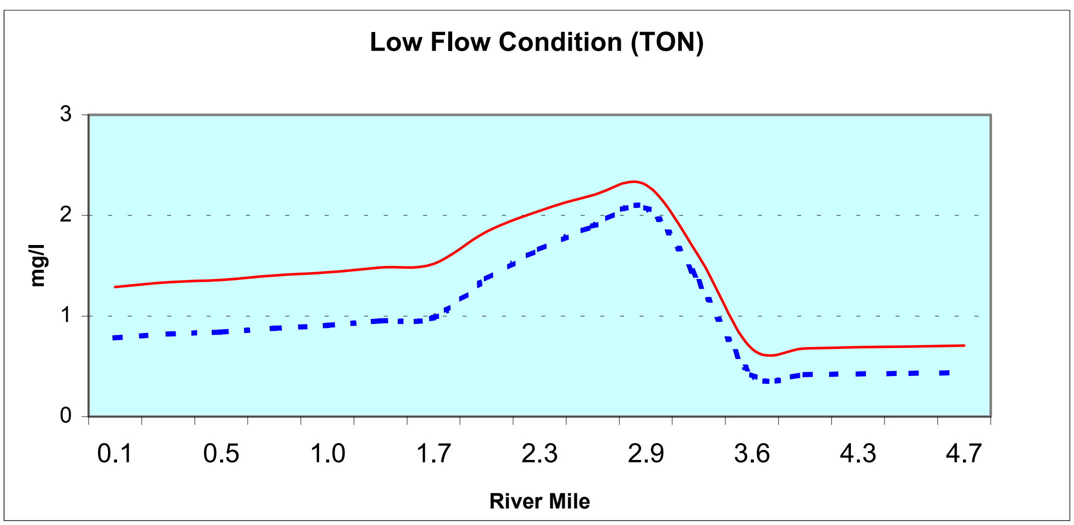


Figure A34: Total Organic Nitrogen vs. River Mile for SCEM TMDL (dash line)

Future TMDL

——————— **Baseline** - - - - - - - - - **TMDL**

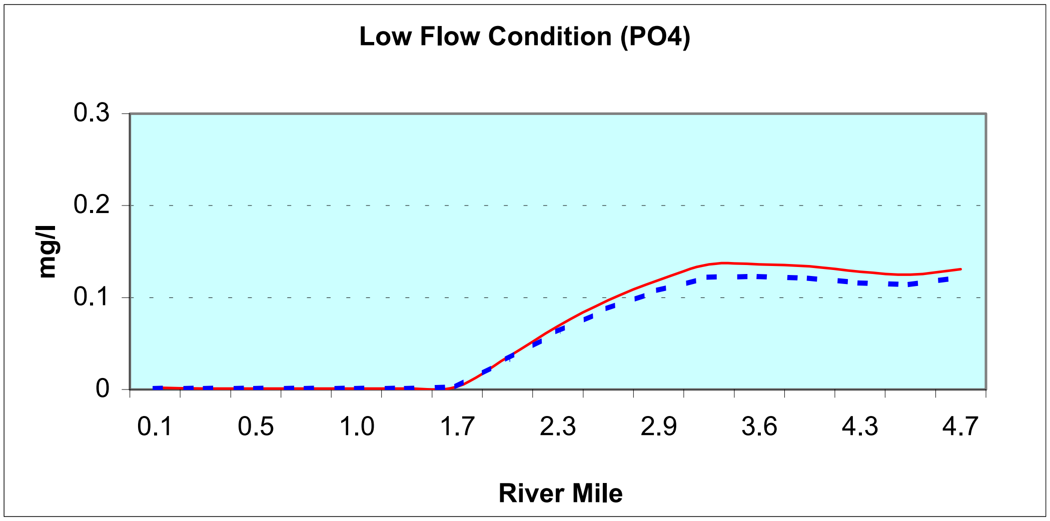


Figure A35: PO4 vs. River Mile for SCEM TMDL (dash line)

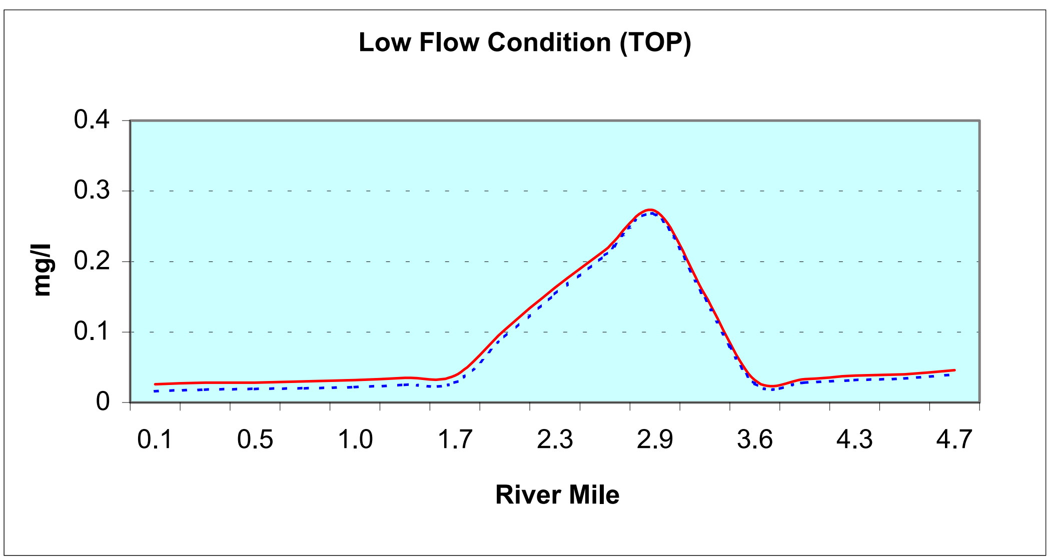


Figure A36: Total Organic Phosphorus vs. River Mile for TMDL (dash line)

***<u>Baseline Condition (Average Annual Flow)</u>* :**

This scenario simulates average annual stream flow (Average Annual Flow) conditions year round. Nonpoint source nutrient loadings were calculated from the product of projected average annual flow and the regional watershed nutrient loading data provided by EPA's Chesapeake Bay Program (2000). Point source loads assume the maximum approved water and sewer plan flow and NPDES permit limits expected in the effluent (4.0 MGD at **Aberdeen WWTP**, 0.05 MGD at **Swan Harbour Dell WWTP**). Results for this scenario, representing the baseline conditions for the average flow seasons, are illustrated in Figures A37-A44. The results indicate a potential algal bloom (Figures A38). Since this scenario was performed under 100% NPS input and NPS is considered as the main contributor of nutrient input during the higher stream flow period, a NPS reduction will be necessary to preserve the stream water quality during average annual flow period.

***<u>TMDL (Average Annual Flow)</u>* :**

This scenario simulates average annual stream flow (Average Annual Flow) conditions year round. Nonpoint source nutrient loadings were calculated from the product of projected average annual flow and 60% of the regional watershed nutrient loading data provided by EPA's Chesapeake Bay Program (2000)(assuming a 40% reduction effort on NPS). Point source loads assume the maximum approved water and sewer plan flow and NPDES permit limits expected in the effluent (4.0 MGD at **Aberdeen WWTP**, 0.05 MGD at **Swan Harbour Dell WWTP**). Results for this scenario, representing the baseline conditions for the average annual flow seasons, are illustrated in Figures A45-A52. The results show no problems for either chlorophyll a or dissolved oxygen (Figures A45-46). It is concluded that the nutrient values set for these loadings will be adequate as the cap for the average annual flow TMDLs.

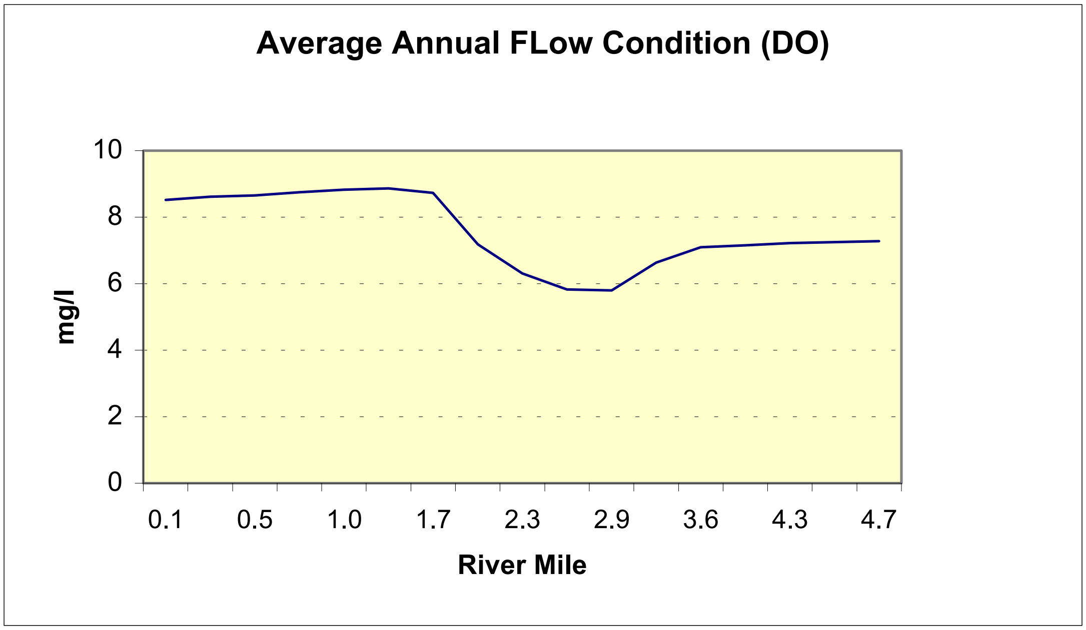


Figure A37: DO vs. River Mile for Average Annual Flow Baseline Condition

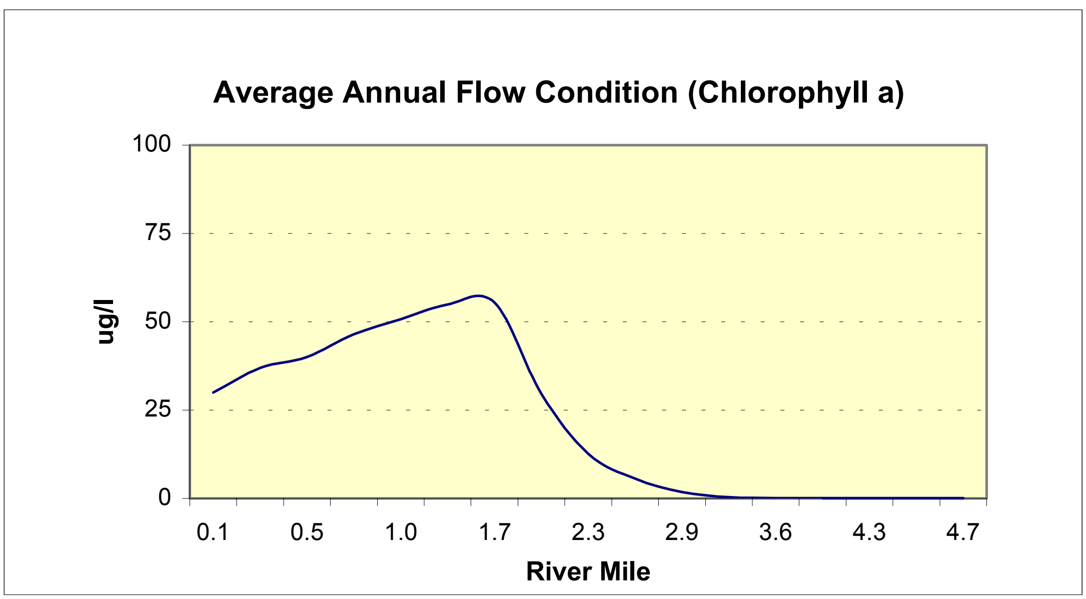


Figure A38: Chlorophyll a vs. River Mile for Average Annual Flow Baseline Condition

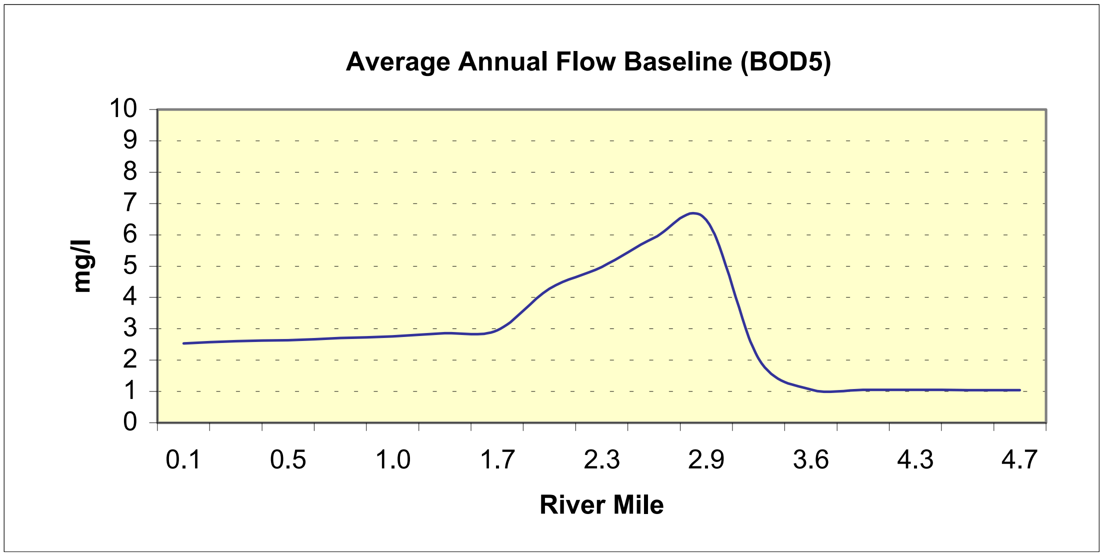


Figure A39: BOD vs. River Mile for SCEM Average Annual Flow Baseline Condition

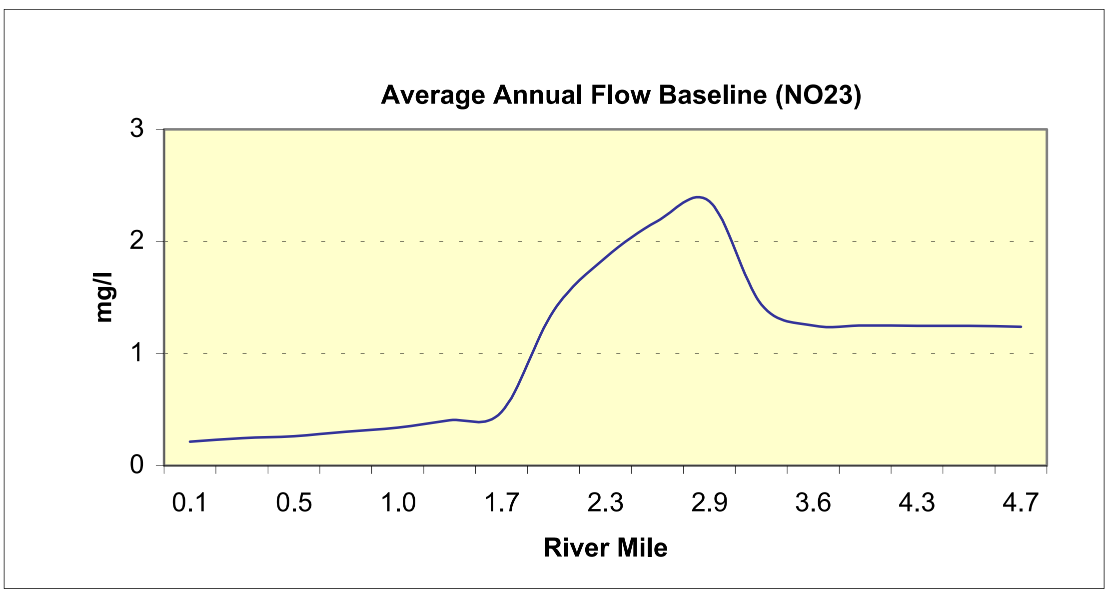


Figure A40: NO_{23} vs. River Mile for SCEM Average Annual Flow Baseline Condition

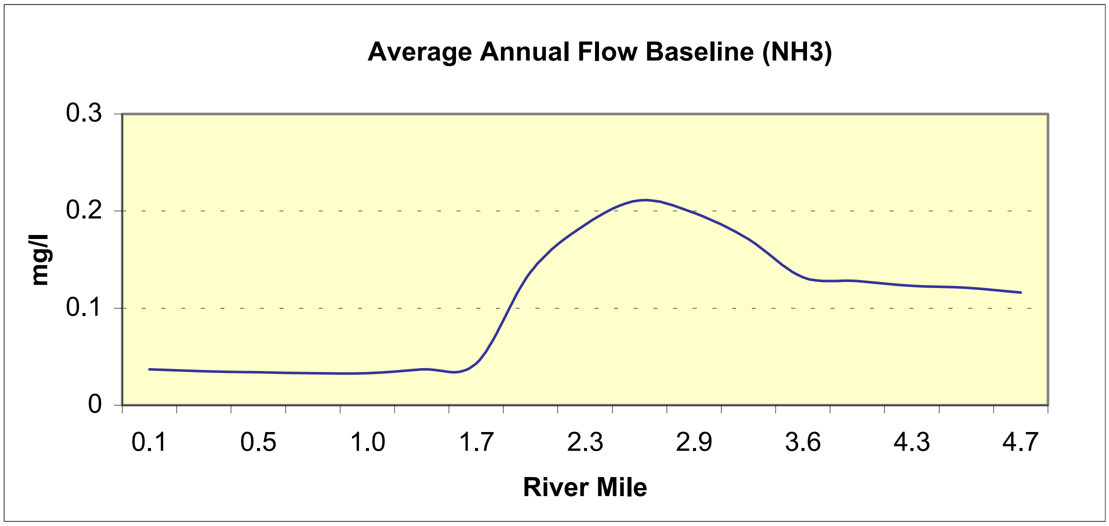


Figure A41: NH_3 vs. River Mile for SCEM Average Annual Flow Baseline Condition

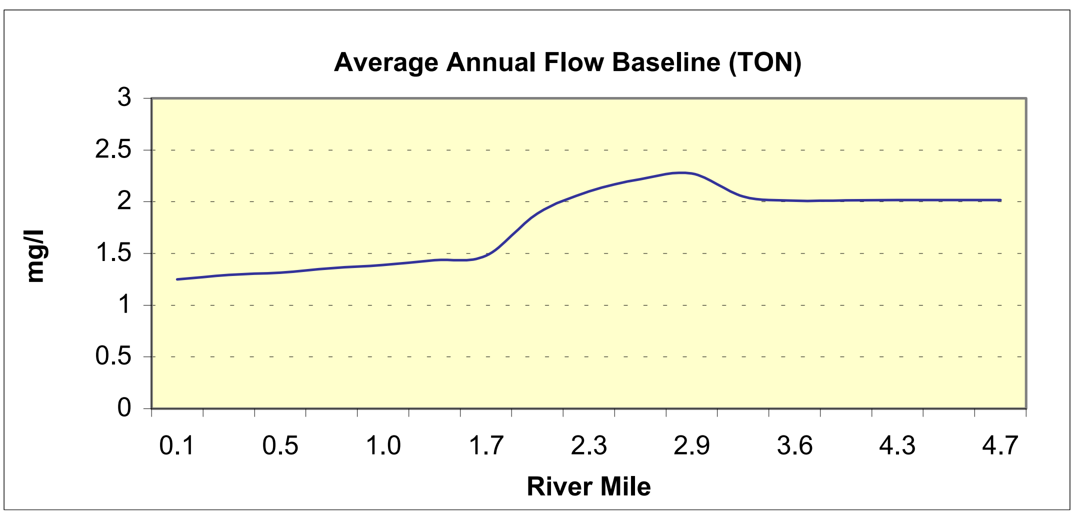


Figure A42: Total Organic Nitrogen vs. River Mile for Average Annual Flow Baseline Condition

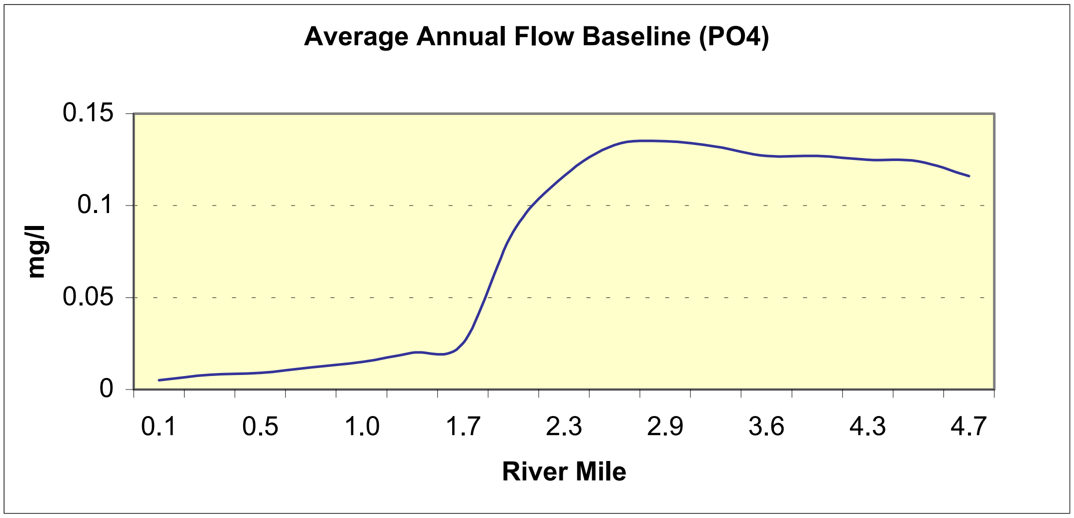


Figure A43: PO_4 vs. River Mile for SCEM Average Annual Flow Baseline Condition

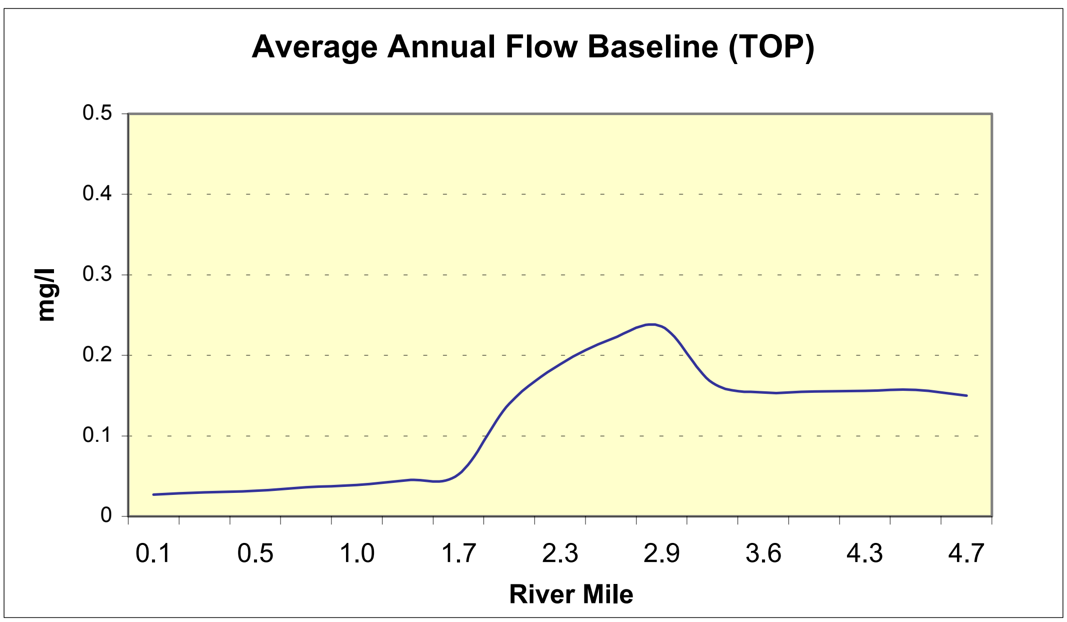


Figure A44: Total Organic Phosphorus vs. River Mile for Average Annual Flow Baseline Condition

Future TMDL

——————— **Baseline** - - - - - - - - - **TMDL**

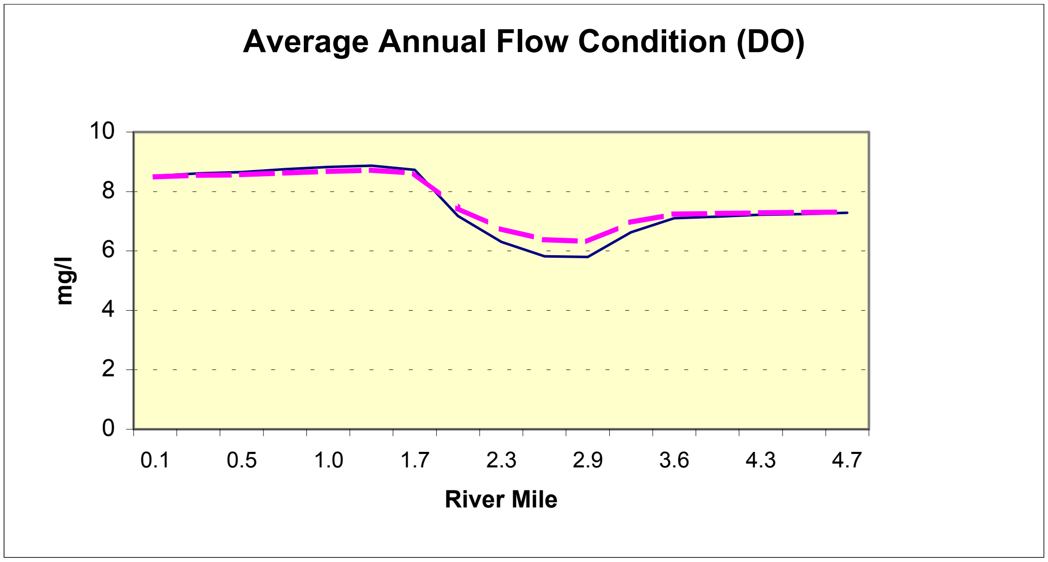


Figure A45: DO vs. River Mile for SCEM TMDL (dash line)

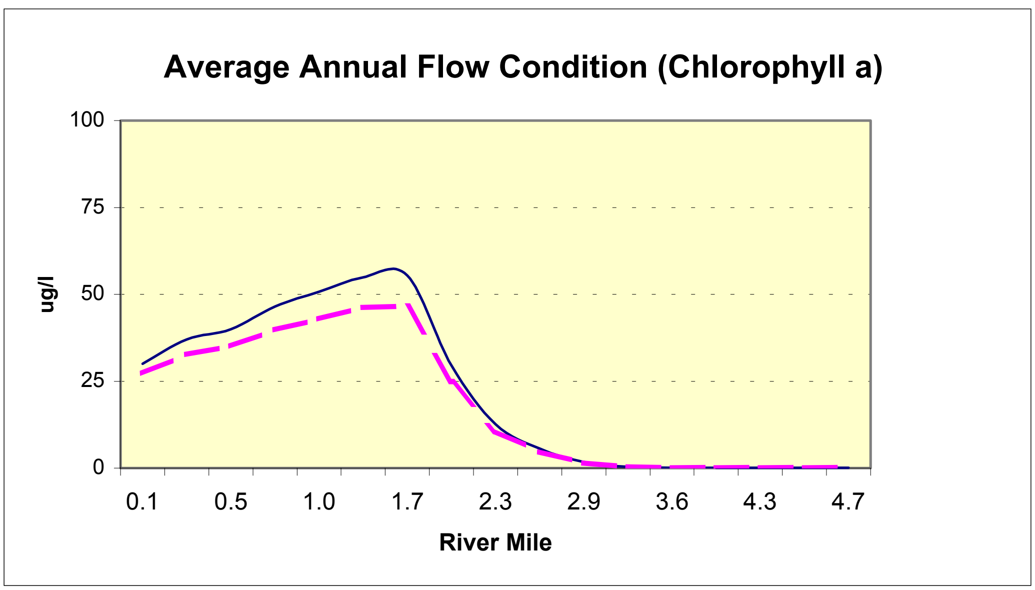


Figure A46: Chlorophyll a vs. River Mile for SCEM TMDL (dash line)

Future TMDL

——————— **Baseline** — — — — — — — — — **TMDL**

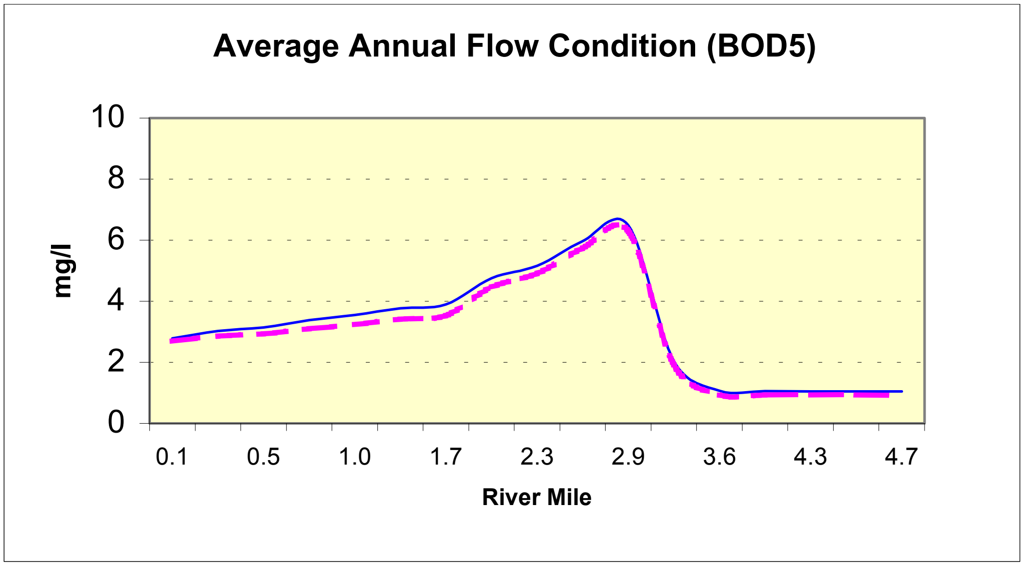


Figure A47: BOD vs. River Mile for SCEM TMDL (dash line)

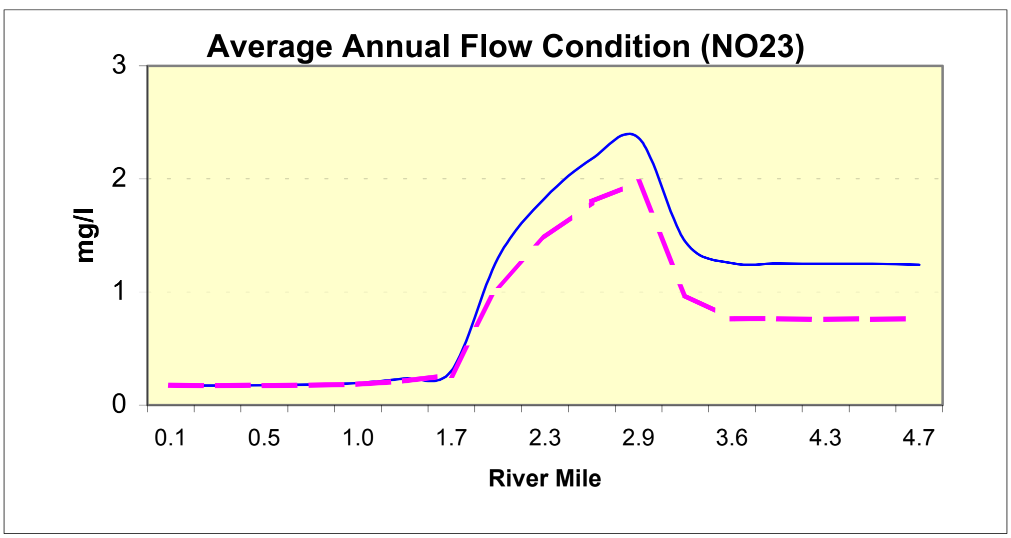


Figure A48: NO_{23} vs. River Mile for SCEM Future Scenario A (dash line)

Future TMDL

———————— **Baseline** – – – – – – – – – **TMDL**

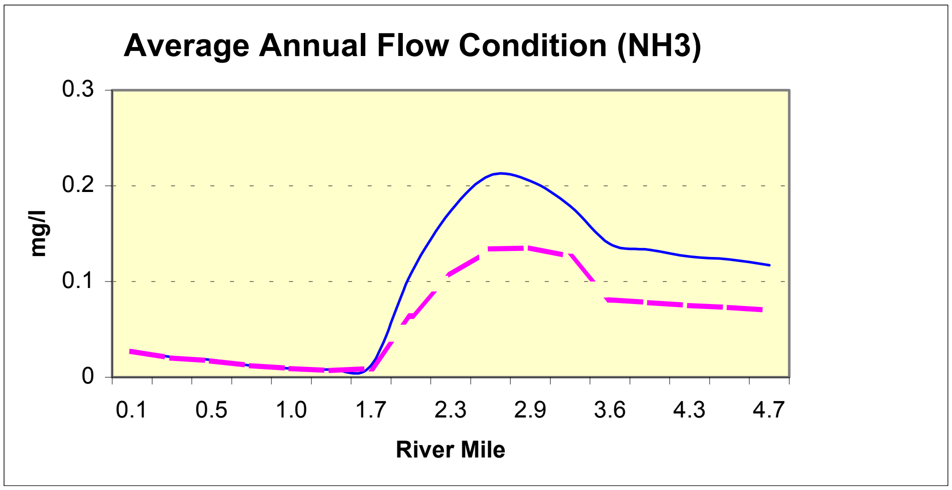


Figure A49: NH_3 vs. River Mile for SCEM TMDL (dash line)

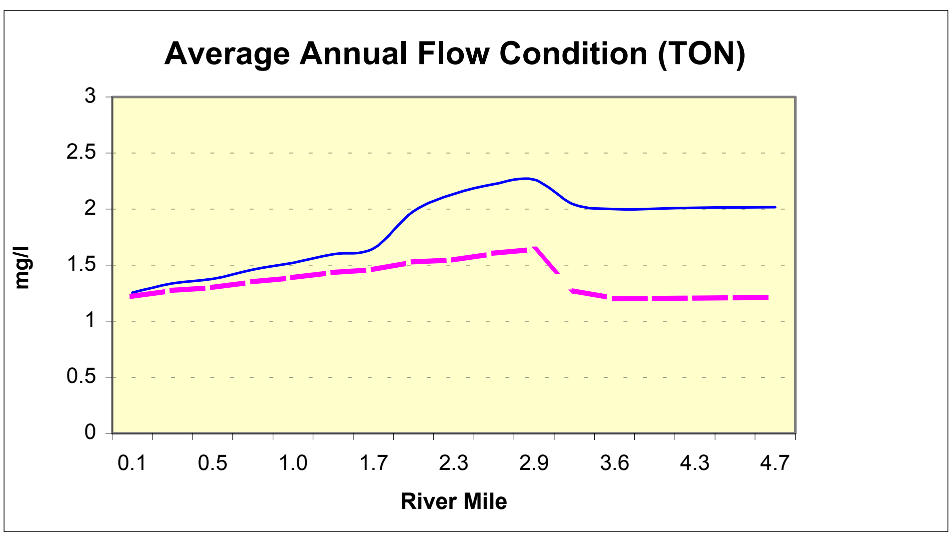


Figure A50: Total Organic Nitrogen vs. River Mile for SCEM TMDL (dash line)

Future TMDL

———————— **Baseline** - - - - - - - - - **TMDL**

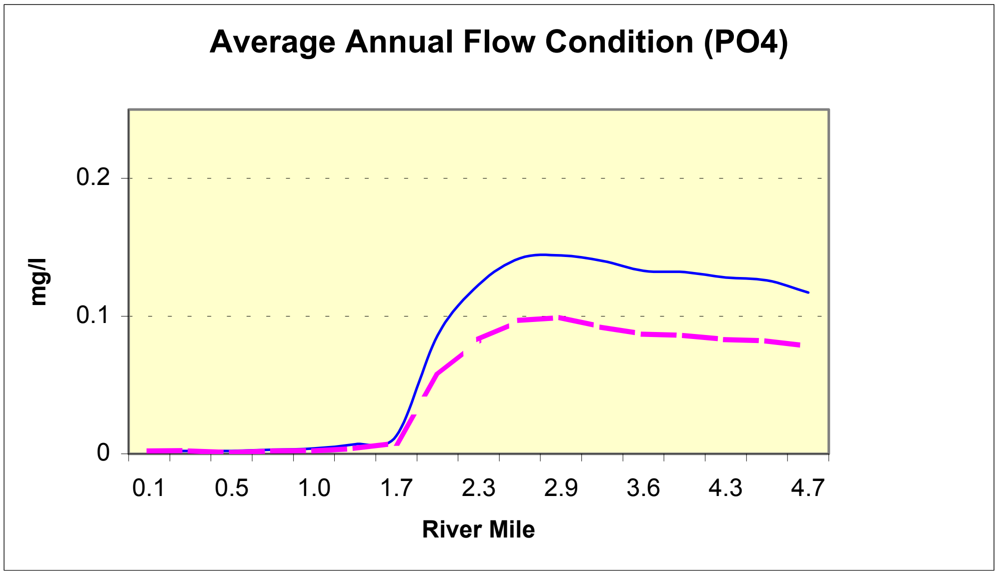


Figure A51: PO4 vs. River Mile for SCEM TMDL (dash line)

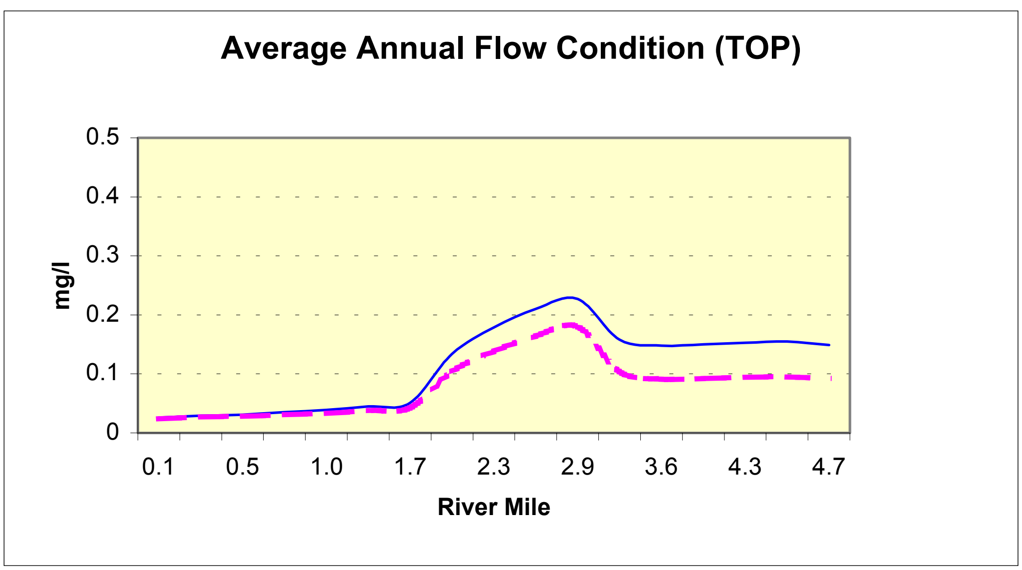


Figure A52: Total Organic Phosphorus vs. River Mile for TMDL (dash line)

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