FINAL

APPENDIX A

Total Maximum Daily Loads of
Nitrogen and Phosphorus for
Mattawoman Creek in
Charles County and
Prince George's County, Maryland

Document version: January 9, 2004

Appendix A

MODELING FRAMEWORK

The computational framework chosen for the modeling of water quality in Mattawoman Creek was the Water Quality Analysis Simulation Program version 5.1 (WASP 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, WASP 5.1 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.

WASP 5.1 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 that is applicable for modeling eutrophication, incorporating eight water quality constituents in the water column (Figure A1) and sediment bed.

WATER QUALITY MONITORING

MDE's Field Operations Program collected physical parameters and water quality samples from Mattawoman Creek during 2001. The physical parameters (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 ½ m from the surface. Samples were placed in plastic bottles and preserved on ice until they were delivered to the University of Maryland Laboratory in Solomons, MD or the Department of Health and 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 Mattawoman Creek. Figures A2 through A9 present low flow water quality profiles along the creek.

INPUT REQUIREMENTS [1]

Model Segmentation and Geometry

The spatial domain of the Mattawoman Creek Eutrophication Model (MCEM) extends from the mouth of Mattawoman Creek to approximately 6 miles up its mainstem. Following a review of the bathymetry for Mattawoman Creek, the model was divided into 32 water quality segments. Figure A10 shows the model segmentation for the development of MCEM. Table A2 lists the volumes, characteristic lengths and interfacial areas of the 32 segments.

Dispersion Coefficients

The dispersion coefficients were calibrated using the WASP 5.1 model and in-stream water quality data from 2001. The WASP5.1 model was set up to model salinity. Salinity is a conservative constituent, which means there are no losses due to reactions in the water. The only source in the system is the salinity from the water at the tidal boundary at the mouth. For the model execution, salinities at all boundaries except the tidal boundary were set to zero. Flows were obtained from a nearby U.S. Geological Survey gage station as explained in more detail below. Figure A12 shows the results of the calibration of the dispersion coefficients based on data observed in September 2001. Because the nature of a fresh tidal river, very low salinity data are commonly observed in Mattawoman Creek. Salinity data collected from September 2001 was the only set of data with a reasonable gradient for dispersion coefficient calibration in MCEM. For this reason, due to very low salinity observed during high flow periods, the same set of dispersion coefficients will be applied to average annual flow condition. Final values of the dispersion coefficients are listed in Table A3.

Freshwater Flows

Freshwater flows were calculated after the Mattawoman Creek drainage basin was delineated into subwatersheds contributing flows consistent with the 32 water quality segments developed for the MCEM (Figures A10 and A11).

In order to make representative flow estimations for model simulation, flow data from five USGS stations located on or adjacent Mattawoman Watershed (USGS gage #01590000, # 01594600, # 01594800, #01658000 and #01661500) were utilized. A low flow for each individual station was determined by obtaining an average value over the 2001 low flow period. A drainage ratio (flow to drainage area) was calculated for each of the USGS stations and then an average of all the flow to area ratios was determined. The $7Q_{10}$ and average annual flows for the individual subwatersheds were determined by obtaining the $7Q_{10}$ flow and average annual flow from the individual reference USGS station and then applying an inverse distance weighting equation suggested by USGS for southern Maryland region to calculate the flow for Mattawoman Creek watershed. Table A4 presents flows from different subwatersheds each flow conditions.

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

Point and Non Point Source Loadings

There are four point sources, Town of Indian Head WWTP (0.5 MGD design capacity), Lackey High School (0.009 MGD design capacity), Brandywine Receiving Station (0.009 MFD) and the Lingafelt Residence (0.00045MGD) contributing loads to Mattawoman Creek. Due to their insignificant flows and locations in the watershed (away from main MCEM segments), loads from Lackey High, Brandywine Receiving Station and the Lingafelt Residence were considered incorporated with the observed NPS loads. The major nonpoint sources considered in MCEM are background flow from the upper watershed and the non-contact cooling water discharged from Naval Surface Warfare Center (note: the cooling water was initially taken from the Mattawoman Creek). NPS loadings for the low flow conditions were estimated as the product of observed nutrient concentrations and estimated flows as described above. Being observed loads, they account for all sources. Average annual loads were calculated as the product of estimated average annual flow and the regional nutrient-loading rate provided by EPA's Chesapeake Bay Program**.**

NPS loads for the calibration of the model were calculated based on the observed data obtained from two water quality stations during the 2001 low flow water quality survey. Data from water quality stations near the upper boundaries are selected to represent the background nutrient conditions. The concentrations of the nutrients nitrogen and phosphorus are modeled in their speciated forms. The WASP5.1 model simulates nitrogen as ammonia (NH_4^+), nitrate and nitrite (NO_{23}), and organic nitrogen (ON); and phosphorus as ortho-phosphate (PO_4) and organic phosphorus (OP). NH_4^+, NO_{23}, and PO_4 represent the dissolved forms of nitrogen and phosphorus. The dissolved forms of nutrients are more readily available for biological processes such as algae growth that can affect chlorophyll *a* levels and DO 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 Mattawoman 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 MCEM reaches based on observed environmental conditions and literature values (Thomann and Muller, 1987). The highest SOD values were assumed to occur near the upper segments of the creek between the confluence of Harrison Cut and Mattawoman Creek. In this region of model segments, the effluent from the Town of Indian Head WWTP, combined with nutrients coming from upstream, is impeded by light tidal activity, and high concentrations of nutrients and organic particles are likely to settle into the sediment.

Kinetic Coefficients

The water column kinetic coefficients are universal constants used in the MCEM model. They are formulated to characterize the kinetic interactions among the water quality constituents. The initial values were taken from past modeling studies of Potomac River (Clark and Roesh, 1978; Thomann and Fitzpatrick, 1982; Cerco, 1985), and of Mattawoman Creek (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.

CALIBRATION & SENSITIVITY ANALYSIS

The EUTRO5.1 model for low flow was calibrated using 2001 Mattawoman Creek water quality survey data. The nutrient loadings from the point sources for calibration were calculated based on observed nutrient concentrations and actual discharged flows. The NPS loadings were calculated based on estimated low flow of the two sampling dates and the observed nutrient concentrations. Figures A13 through A20 show the results of the calibration of the model for low flow conditions. Results from Figure A11 suggest that the MCEM has successfully captured the trend of the DO in the creek. The model prediction is also consistent with the general trend of chlorophyll *a* showing a higher potential for algal production in the upper segments in MCEM. The general trend for the rest of the observed nutrient values along the model segments were also captured by the model's prediction.

SYSTEM RESPONSE

The EUTRO5.1 model of Mattawoman 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 DO in the stream. The responses of various scenarios from the MCEM were analyzed to determine the TMDLs of nitrogen and phosphorus for Mattawoman Creek during low and average annual flow conditions.

Model Run Descriptions

Baseline Condition (Low Flow): This first scenario represents the baseline conditions of the stream at a simulated critical low flow in the river. The method of estimating the critical low flow is described in Appendix A. The scenario simulates a critical condition when the river system is poorly flushed, and sun light and warm water temperatures are most conducive to create the water quality problems associated with excessive nutrient enrichment.

The nutrient concentrations for the first scenario were calculated using observed data collected during 2001 low flow period. The low flow NPS loads were computed as the product of the observed concentrations and estimated critical low flow ($7Q_{10}$). These low flow NPS loads integrate all natural and human induced sources, including direct atmospheric deposition, loads from septic tanks, which are associated with river base flow during low flow conditions. The NPS loads in the MCEM also include the non-contact cooling water and the stormwater discharge from the Indian Head Naval Surface Warfare Center. For point source loads from wastewater treatment plants, these baseline conditions assume maximum permitted flow from the major point source (Town of Indian Head WWTP, 0.5 MGD) with the observed effluent nutrient during 2001 summer seasons (total nitrogen of 15 mg/l, total phosphorus of 3.7 mg/l) and maximum permitted biochemical oxygen demand (BOD) concentration (16 mg/l). Nutrient loads from other less significant point sources (Lackey High School, Brandywine Site and the Lingafelt Residence) are assumed at their current permitted flows with effluent parameters expected to occur at their current capacities.

TMDL (Low Flow): This second scenario represents the future condition of maximum allowable loads during critical low stream flow. The stream flow is the same as that used in the first scenario. This scenario simulates an estimated 40% reduction in overall NPS nitrogen and phosphorus input from the watershed. In this future condition scenario, reductions in nutrient fluxes and oxygen demand from the sediment were assumed corresponding to the percentage reduction of nutrient input from the nonpoint sources. The point source loads from the Town of Indian Head WWTP assume maximum design flow with total nitrogen controlled at 10 mg/l and total phosphorus at 3 mg/l. The loads from other less significant point sources (Lackey High School, Brandywine Site and the Lingafelt Residence) are assumed at their current permitted flows with effluent parameters expected to occur at their current capacities with no additional control. Details of this load allocation are described further in the technical memorandum entitled "*Nutrient Point Sources in the Mattawoman Creek Watershed*".

Baseline Condition (Average Annual Flow): This third scenario represents the baseline conditions of the stream at a simulated average annual condition in the river. The model predict the stream's response for nutrient input at a year round condition. The method of estimating the average annual flow is described above.

For point source loads from wastewater treatment plants, these baseline conditions assume maximum permitted flows from the major point sources (Town of Indian Head WWTP, 0.5 MGD) with the observed effluent nutrient from the 2001 Summer data (total nitrogen of 15 mg/l, total phosphorus of 3.7 mg/l, DO of 6 mg/l) and maximum permitted biochemical oxygen demand (BOD) concentration (30 mg/l). The loads from other less significant point sources (Lackey High School, Brandywine Site and the Lingafelt Residence) are assumed at their current permitted flows with effluent parameters expected to occur at their current capacities.

The total NPS loads were calculated using loading rates for different land use from the EPA Chesapeake Bay Program Phase IV watershed model and land use information from 2000 Maryland Department of

Development (MDP) data. These nutrient loads account for contributions from atmospheric deposition, agricultural, forest and urban lands. The NPS loads in the MCEM also account for the non-contact cooling water discharge from the Indian Head Naval Surface Warfare Center. Because the source of the water is from the Potomac River and its nature is not altered during the cooling process, it is considered as a nonpoint source. For loads from wastewater treatment plants, these baseline conditions assume maximum allowable effluent flow (based on plant designed flow approved by water and sewer plan) with their current National Pollutant Discharge Elimination System (NPDES) permitted concentrations as the nutrient parameters.

TMDL (Average Annual Flow): This fourth scenario represents the future condition of maximum allowable loads during average annual flow condition. The stream flow in this scenario is the same as that used in the third scenario. This scenario simulates an estimated 40% overall reduction in NPS nitrogen and phosphorus input from the watershed. The point source loads assume maximum allowable flow (0.5 MGD) with total nitrogen and total phosphorus at 15 mg/l and 3 mg/l respectively from Town of Indian Head WWTP. The loads from other less significant point sources (Lackey High School, Brandywine Site and the Lingafelt Residence) are assumed at their current permitted flows with appropriate parameters expected to occur at their capacities. In this scenario, reductions in nutrient fluxes and oxygen demand from the sediment were assumed corresponding to the percentage reduction of nutrient input from the nonpoint sources. Details of the load allocations are described further in the technical memorandum entitled "*Nutrient Point Sources in the Mattawoman Creek Watershed*" and "*Significant Nutrient Non Point Sources in the Mattawoman Creek Watershed*".

4.4 Scenario Results

This section describes the results of the model scenarios described in the previous section. The MCEM results presented in this section are daily minimum DO concentrations. These minimum DO concentrations account for diurnal fluctuations caused by photosynthesis and respiration of algae.

Baseline Condition (Low Flow) :

This scenario simulates critical low stream flow ($7Q_{10}$) conditions during the summer season. Point source loads assume maximum approved water and sewer plan flow and observed effluent nutrient concentrations during 2001 Summer from Town of Indian Head WWTP (0.5 MGD at Town of Indian WWTP). The loadings from the other three point sources were incorporated with the nonpoint sources using the observed water quality parameters (e.g., nutrient concentrations) based on the 2001 survey. Results for this scenario, representing the baseline condition for summer low flow, are illustrated in Figures A21 through A28. Figure A22 indicates that the peak chlorophyll *a* levels reach well above 50 µg/l under critical condition of temperature and flows in the upper segments. Even the DO level is above the 5.0 mg/l in all segments, there is still a potential risk of low DO situation in the segments with high chlorophyll a concentration due to the "diurnal swing". A TMDL scenario, presented below, establishes maximum allowable loads that address these apparent problems.

TMDL (Low Flow):

This scenario simulates the future condition of maximum allowable loads for critical low stream flow ($7Q_{10}$) conditions during summer season to meet the water quality in Mattawoman Creek. Results for the TMDL (represented by the dash line) are illustrated in comparison to the baseline condition (represented by the solid line) in Figure A29 through A36. Under the nutrient load reduction conditions described above for this scenario, the results show that chlorophyll *a* concentrations are below the levels of 50 µg/l along the entire length of Mattawoman Creek. The DO concentrations predicted in all segments are also above the water quality criterion of 5.0 mg/l. With the algae level being controlled at low concentration, the potential risk of low DO condition caused by "diurnal swing" has been significantly reduced.

Baseline Condition (Average Annual Flow):

This scenario simulates average annual flow conditions. NPS nutrient loads are based on loading rates for different land use from the EPA Chesapeake Bay Program Phase IV watershed model and land use information from 2000 MDP data. Point source loads from wastewater treatment plants assume maximum approved water and flow and observed effluent nutrient concentrations during Summer 2001 (0.5 MGD at Town of Indian Head WWTP). Results for this scenario, representing the baseline condition for high flow seasons, are illustrated in Figure A37 through A44. The results (Figure A38) indicate that the peak chlorophyll *a* levels will exceed 50 µg/l under average annual flow condition in the lower middle segments. The DO level is above the 5.0 mg/l in all segments. A TMDL scenario, presented below, establishes maximum allowable loads that address these apparent problems.

TMDL (Average Annual Flow Condition):

This scenario simulates the future condition of maximum allowable loads for average annual flow conditions to meet the water quality standard for Mattawoman Creek. Results for the TMDL are illustrated in comparison to the appropriate baseline condition (solid line) in Figure A45 through A52. Under the nutrient load reduction conditions described above for this scenario, the results indicate that chlorophyll *a* concentrations in the entire length of the model segments are below the levels of 50 µg/l. Results also indicate that the minimum concentrations of DO along the length of the river are above the water quality criterion of 5.0 mg/l.

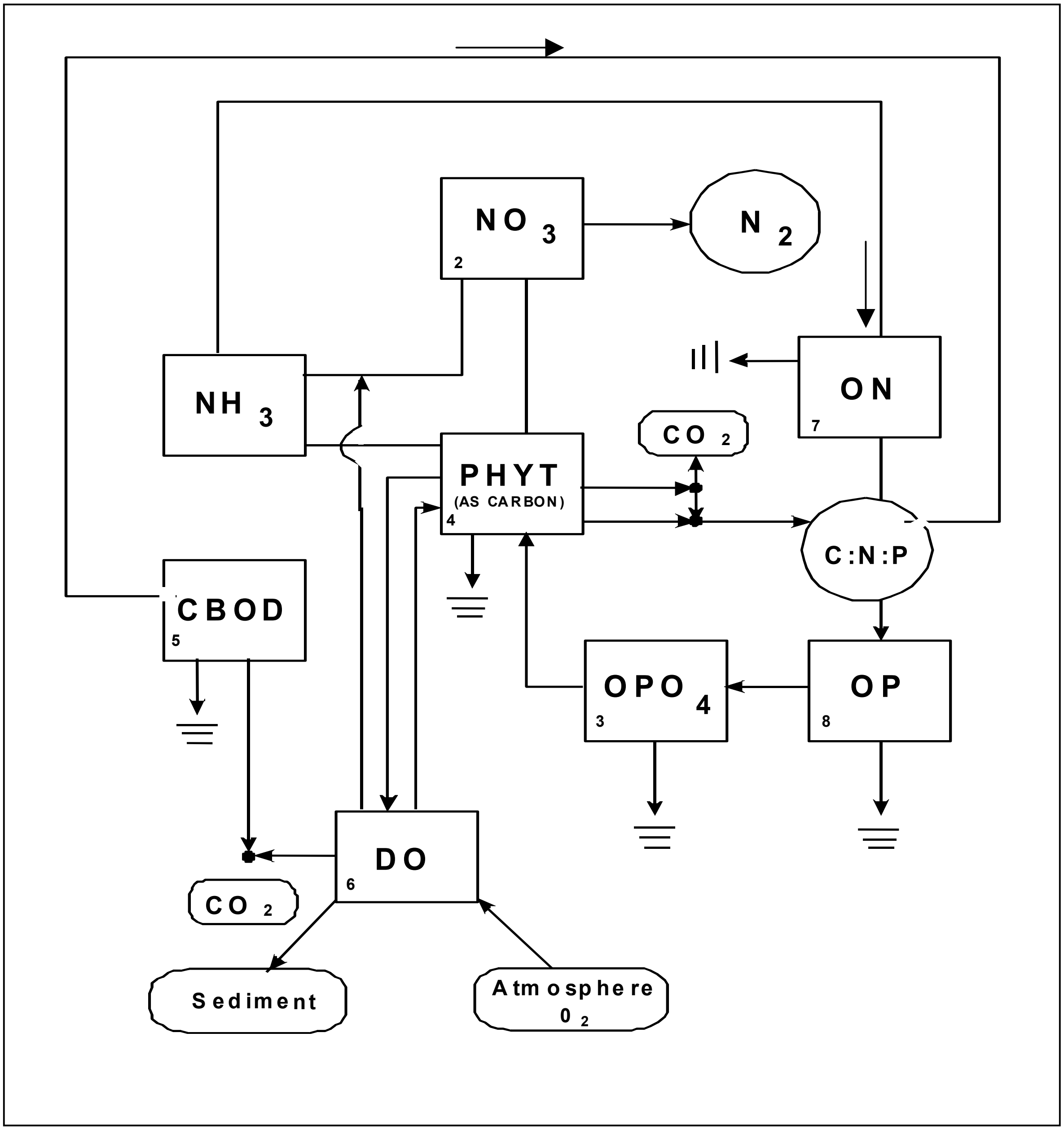


Figure A1. State Variables and Kinetic Interactions in EUTRO5

Table A1: Field and Laboratory Protocols

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

Table A2: Physical characteristic of segments used in MCEM

Segment	*Length (m)*	*Width (m)*	*Depth (m)*	*Volume (m^3)*	*X-Area (m^2)*
1	481	1261	1.83	1109970	2308
2	403	1198	1.83	883513	2192
3	465	912	1.83	776066	1669
4	497	326	1.53	247894	499
5	438	419	2.75	504686	1152
6	324	666	2.59	558881	1725
7	556	989	1.31	720348	1296
8	548	564	1.22	377068	688
9	492	486	0.92	219983	447
10	330	471	0.76	118127	358
11	335	194	1.21	78638	235
12	436	196	0.91	77765	178
13	337	530	1.21	216118	641
14	559	356	1.21	240795	431
15	339	557	1.06	200152	590
16	460	424	0.91	177486	386
17	453	359	0.91	147991	327
18	432	535	0.91	210319	487
19	334	311	0.61	63363	190
20	481	119	3.03	173434	361
21	416	468	1.82	354332	852
22	326	571	1.82	338786	1039
23	328	618	2.72	551355	1681
24	373	600	2.72	608736	1632
25	619	114	3.3	233167	376
26	397	80	2.4	76608	192
27	1210	172	1.2	249852	206
28	438	9	0.8	3136	7
29	182	5	0.3	265	1.5
30	188	166	1.21	37762	201
31	258	376	0.61	59175	229
32	370	292	0.46	49698	134

Table A3: Dispersion Coefficients used in the MCEM

Segment Pair	Dispersion Coefficient (m^2/sec)
0-1	3
1-2	3
2-3	3
3-4	3
4-5	3
5-6	3
6-7	2
7-8	2
8-9	2
9-10	2
9-13	2
10-11	2
11-12	2
12-13	2
13-14	2
13-17	2
14-15	2
15-16	2
16-17	1.5
17-18	1.5
18-19	1.5
18-20	1.5
19-21	1.5
20-21	1.5
21-22	1
22-23	0.9
23-24	0.8
23-25	0.4
25-26	0.4
26-27	0.2
27-28	0.2
28-29	0.0001
30-12	2
31-6	2
32-5	2

Table A4: Subwatersheds NPS flow contributions in MCEM

(A) Subwatershed Drainage

Segment	Drainage Area (sq.mile)	$7Q_{10}$ Flow (m^3/sec)	Average Annual Flow (m^3/sec)
1	0.12	0.0002	0.003
2	0.15	0.0002	0.004
3	0.15	0.0003	0.004
4	0.25	0.0004	0.006
5	0.15	0.0003	0.004
6	0.02	0.0001	0.001
7	0.04	0.0001	0.001
8	1.62	0.0028	0.04
10	0.13	0.0002	0.003
11	0.28	0.0005	0.007
12	0.07	0.0001	0.002
14	0.04	0.0001	0.001
15	0.16	0.0003	0.004
16	0.11	0.0002	0.003
17	0.04	0.0001	0.001
18	0.20	0.0004	0.005
19	0.07	0.0001	0.002
20	0.40	0.0007	0.01
21	0.31	0.0005	0.006
22	0.55	0.001	0.014
23	2.35	0.004	0.058
24	0.12	0.0002	0.003
25	0.15	0.0003	0.004
26	0.22	0.0004	0.006
27	82.48	0.1448	2.039
28	0.09	0.0001	0.002
29	0.02	0.0001	0.001
30	0.39	0.0007	0.01
31	4.00	0.007	0.099
32	0.14	0.0002	0.003

(B) NSWC non-contact cooling water flow input in MCEM model segment

Segment	Average Flow (MGD)	Average Flow (m^3/sec)
5	0.172	0.075
21	1.115	0.049
30	0.494	0.022

Table A5: Environmental parameters for MCEM low flow calibration

Segment	K_e (m^{-1})	T(^oC)	SOD (gO_2/m^2.day)	NH_4^+ flux (mg/m^2-day)	PO_4^{3-} flux (mg/m^2-day)
1	6.4	25	2.0*	20**	2.0**
2	6.4	25	0.5	10	0.5
3	6.4	25	0.5	10	0.5
4	6.4	25	0.5	10	0.5
5	6.4	25	0.5	10	0.5
6	6.4	25	0.5	10	0.5
7	6.4	25	0.5	10	0.5
8	6.4	25	0.5	10	0.5
9	6.4	25	0.5	10	0.5
10	6.4	25	0.5	10	0.5
11	6.4	25	0.5	10	0.5
12	6.4	25	0.5	10	0.5
13	6.4	25	0.5	10	0.5
14	6.4	25	0.5	10	0.5
15	6.4	25	0.5	10	0.5
16	6.4	25	0.5	10	0.5
17	6.4	25	0.5	10	0.5
18	6.4	25	0.5	10	0.5
19	6.4	25	0.5	10	0.5
20	6.4	28	0.5	10	0.5
21	6.4	28	0.5	10	0.5
22	6.4	28	0.5	10	0.5
23	6.4	28	0.5	10	0.5
24	6.4	28	0.5	10	0.5
25	6.4	28	0.5	10	0.5
26	6.4	28	1.0	10	1.0
27	4.4	28	1.0	40	1.0
28	4.0	22	1.0	60	1.0
29	4.0	22	0.5	20	0.5
30	6.0	28	0.5	10	0.5
31	6.0	28	0.5	10	0.5
32	6.0	28	0.5	10	0.5

*Estimation base on model calibration and values in the technical report prepared in 1987 by Hydro Qual to Metropolitan Washington Council of Government on the evaluation of sediment oxygen demand in the Potomac estuary.

**Estimation base on model calibration and the range for sediment nutrient release rates for Potomac estuary illustrated in “Principals of Surface Water Quality Modeling and Control” by Thomann and Muller (1987).

Table A6: Eutro 5 Kinetic Coefficients used in MCEM

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	0.125 *Day* -1 at 20^{o}C
temperature coefficient	K1RT	1.08
Nonpredatory phytoplankton death rate	K1D	0.025 *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 $mg\ PO_4$*-P/ mg C*
Half-saturation constants for phytoplankton growth		
Nitrogen	KMNG1	0.015 *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	0.5
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	1.047
Reaeration rate constant	K2	0.5 *day* -1 at 20^o C
Mineralization rate of dissolved organic nitrogen	K71C	0.025 *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		0.09 m/day
Organic settling velocity		0.09 m/day

Table A7: Parameters used for the Town of Indian Head WWTP in MCEM Scenarios*

Parameter	*Calibration*	*Baseline (Low)*	*Baseline(Annual)*	*TMDL(low)*	*TMDL(Annual)*	*Unit*
Flow (Design)	0.41	0.5	0.5	0.5	0.5	*MGD*
NH_3	0.75	0.75	0.75	0.5	0.75	*mg/l*
NO_{23}	12	12	12	8	12	*mg/l*
PO_4	3.46	3.46	3.46	2.8	2.8	*mg/l*
Chlorophyll a	2	2	2	2	2	*µg/l*
BOD	10	16	30	16	30	*mg/l*
DO	6.6	6.6	6.6	6.6	6.6	*mg/l*
Organic N	2.25	2.25	2.25	1.5	2.25	*mg/l*
Organic P	0.22	0.22	0.22	0.2	0.2	*mg/l*

*** Parameters were estimated through the average effluent data from Indian Head WWTP DMR in 2001 Summer**

Table A8: Non Point sources concentrations used in various scenarios in MCEM

Low Flow Calibration*

Segment	oxygen	CBOD	NH4	NO23	ORG-N	PO4	ORG-P	CHLA
5	5.455	2.510	0.004	0.065	0.306	0.005	0.010	0.014
8	6.154	2.831	0.004	0.003	0.346	0.005	0.011	0.016
21	31.676	14.571	0.021	0.422	1.779	0.027	0.059	0.081
22	10.486	4.824	0.007	0.005	0.589	0.009	0.020	0.027
27	314.206	144.535	0.209	0.155	17.650	0.268	0.587	0.804
30	14.034	6.456	0.009	0.187	0.788	0.012	0.026	0.036
31	15.223	7.003	0.010	0.008	0.855	0.013	0.028	0.039
unit	Kg/day	Kg/day	Kg/day	Kg/day	Kg/day	Kg/day	Kg/day	Kg/day

Baseline Low Flow ($7Q_{10}$)*

Segment	oxygen	CBOD	NH4	NO23	ORG-N	PO4	ORG-P	CHLA
5	5.06	2.326	0.003	0.065	0.284	0.004	0.009	0.013
8	0.85	0.85	0.001	0.001	0.103	0.002	0.003	0.005
21	31.68	14.57	0.021	0.422	1.779	0.027	0.059	0.081
22	0.46	0.21	0.000	0.000	0.026	0.000	0.001	0.001
27	9.37	4.31	0.006	0.005	0.526	0.008	0.017	0.024
30	14.03	6.46	0.009	0.187	0.788	0.012	0.026	0.036
31	4.55	2.09	0.003	0.002	0.255	0.004	0.008	0.012
Unit	Kg/day	Kg/day	Kg/day	Kg/day	Kg/day	Kg/day	Kg/day	Kg/day

Baseline Average Annual Flow*

Segment	oxygen	CBOD	NH4	NO23	ORG-N	PO4	ORG-P	CHLA
5	6.665	3.066	0.048	0.470	0.173	0.043	0.013	0.018
8	25.877	11.903	0.597	5.219	2.131	0.482	0.155	0.066
21	31.676	14.571	0.204	2.126	0.642	0.109	0.044	0.081
22	44.096	20.284	0.233	2.034	0.740	0.206	0.062	0.113
27	1317.847	606.210	26.185	206.090	99.112	15.914	6.546	3.374
30	14.034	6.456	2.543	22.727	7.511	1.373	0.546	0.036
31	64.016	29.448	0.287	21.383	0.834	0.175	0.064	0.164
Unit	Kg/day	Kg/day	Kg/day	Kg/day	Kg/day	Kg/day	Kg/day	Kg/day

** Load contributions to Segment 5, 21 and 30 are combinations of stormwater and non-contact cooling water from Naval Surface Warfare Center.*

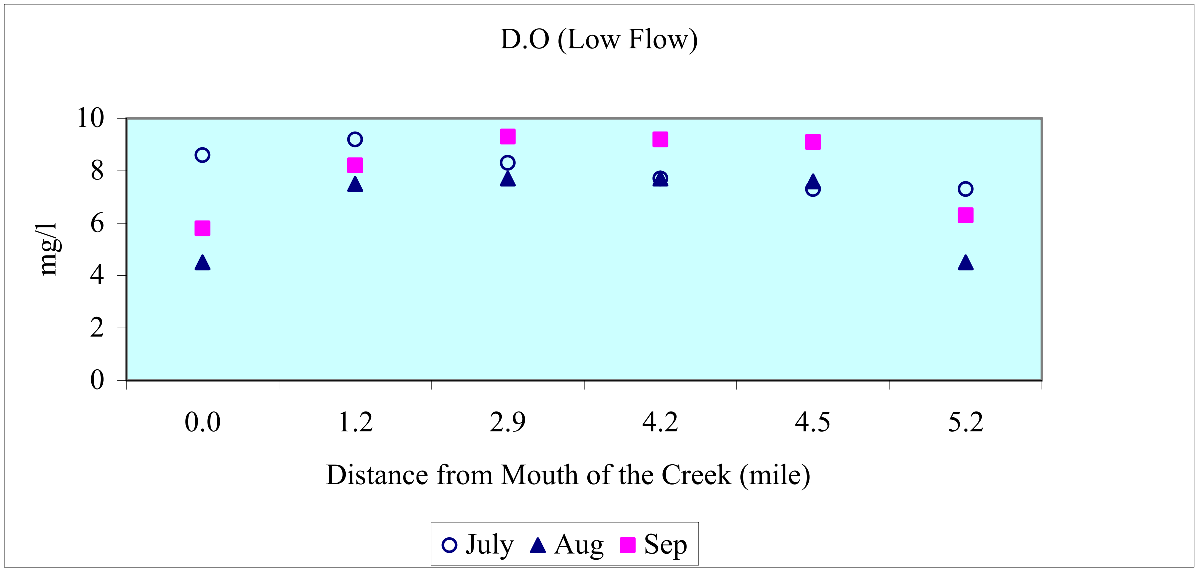


Figure A2: Longitudinal Profile of DO Data from 2001 Mattawoman Creek Water Quality Survey

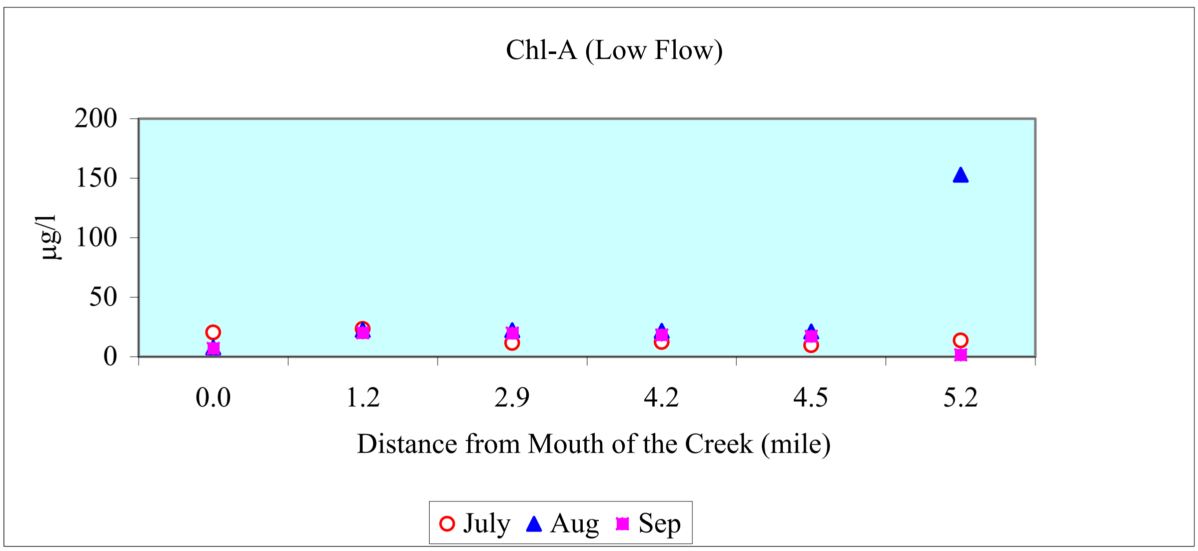


Figure A3: Longitudinal Profile of Chlorophyll *a* Data from Mattawoman Creek Water Quality Survey

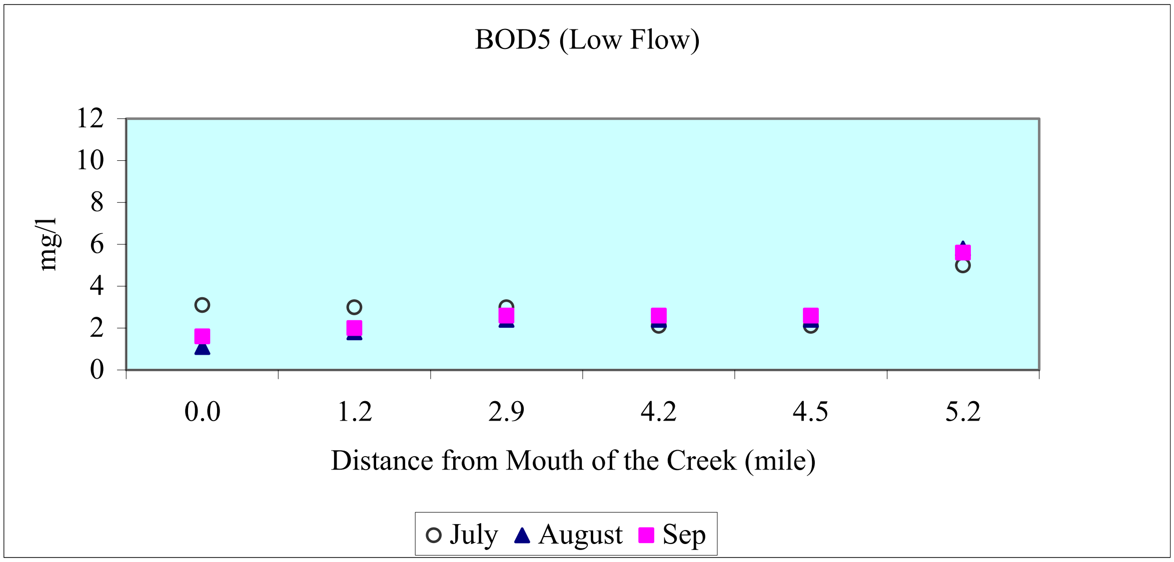


Figure A4: Longitudinal Profile of BOD Data from 2001 Mattawoman Creek Water Quality Survey

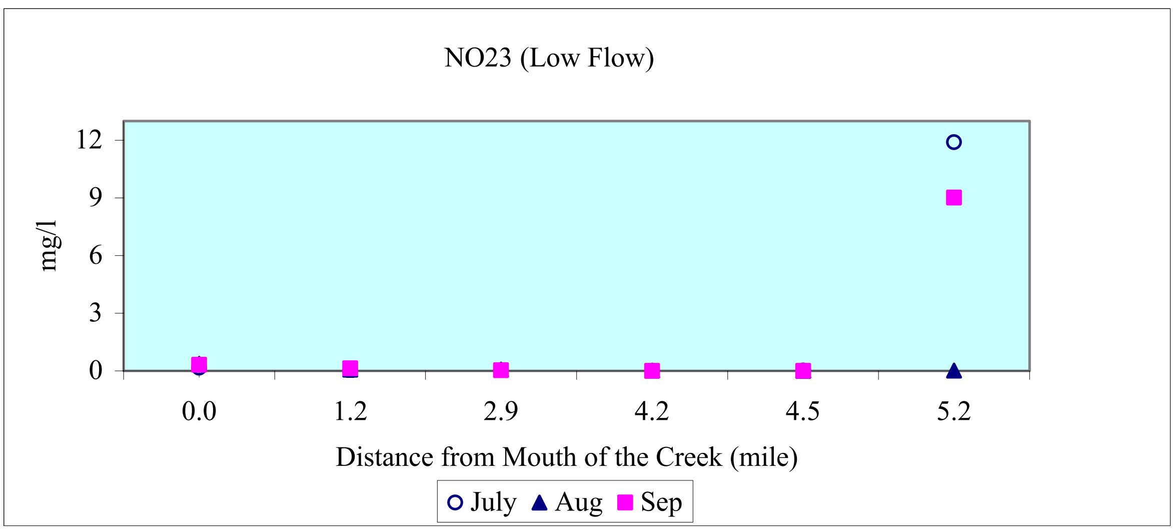


Figure A5: Longitudinal Profile of NO_{23} Data from 2001 Mattawoman Creek Water Quality Survey

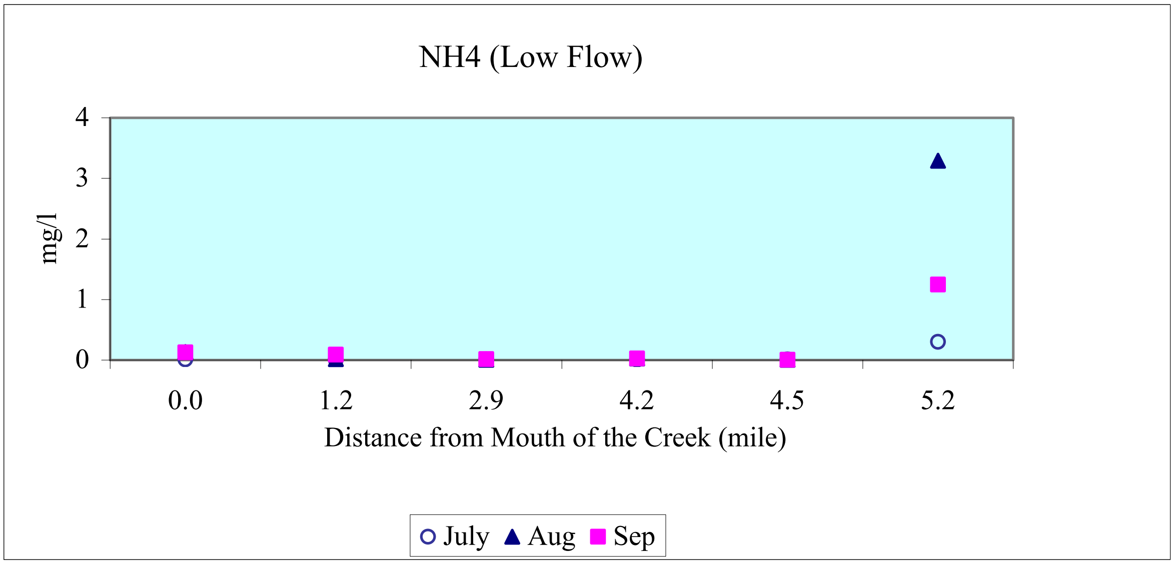


Figure A6: Longitudinal Profile of NH_3 Data from 2001 Mattawoman Creek Water Quality Survey

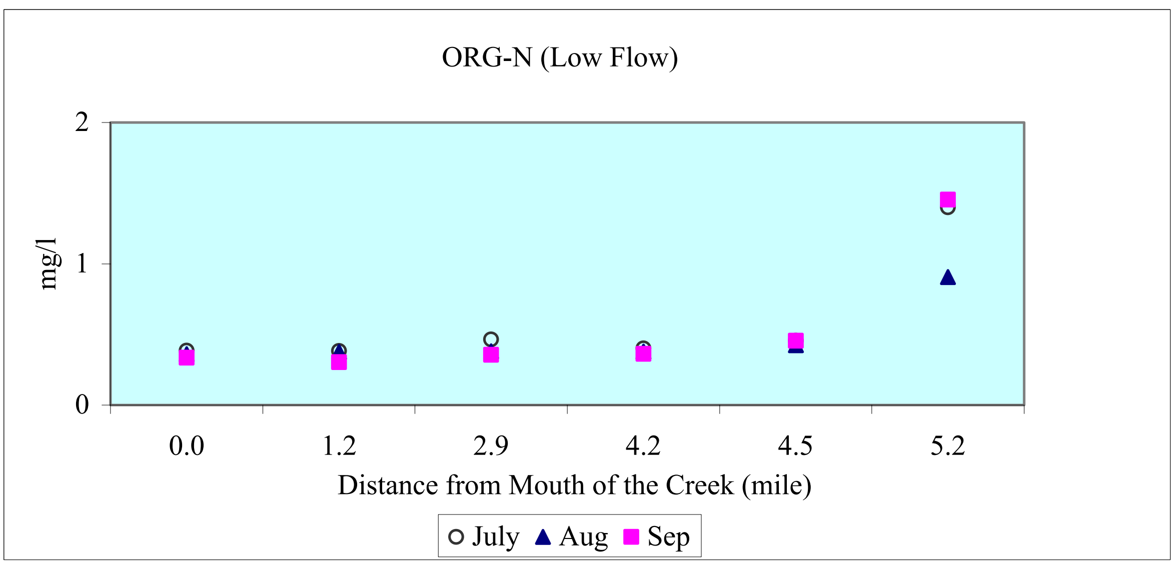


Figure A7: Longitudinal Profile of Total Organic Nitrogen Data from 2001 Mattawoman Creek Water Quality Survey

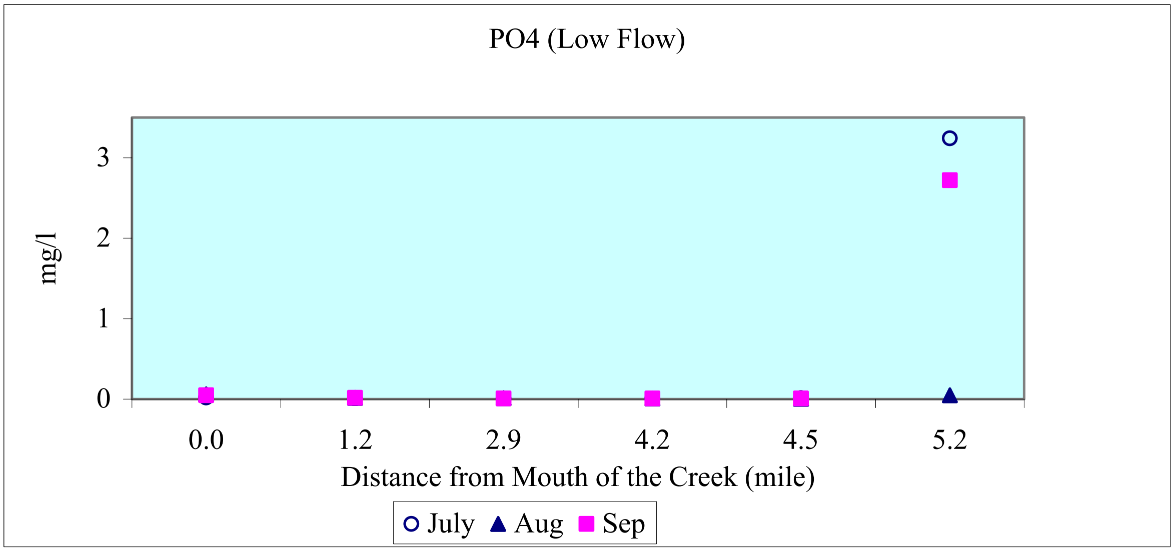


Figure A8:Longitudinal Profile of PO4 from 2001 Mattawoman Creek Water Quality Survey

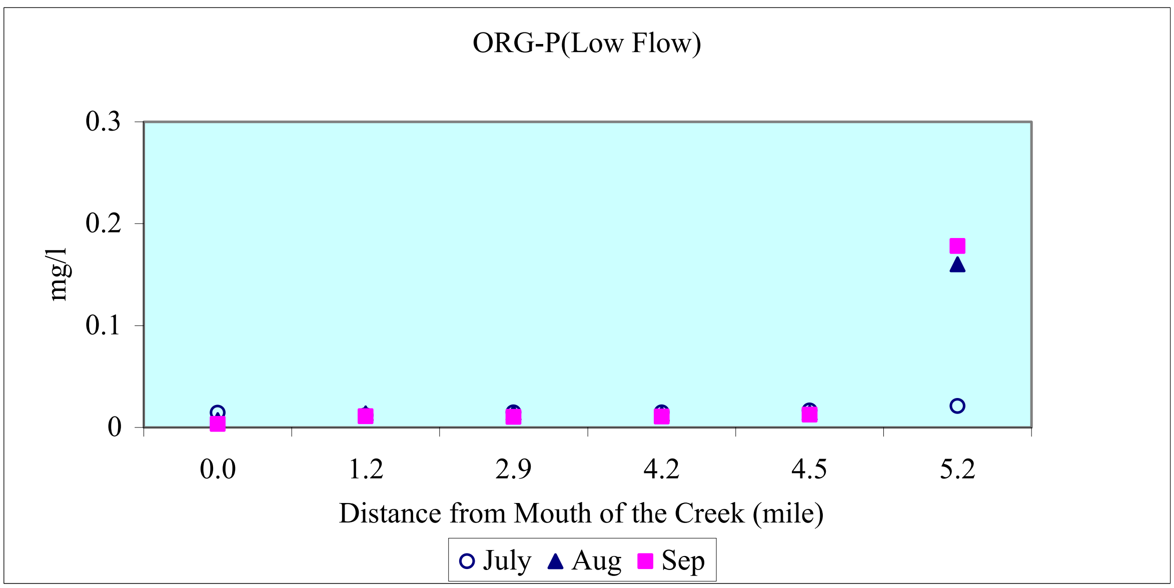


Figure A9: Longitudinal Profile of Total Organic Phosphorus Data from 2001 Mattawoman Creek Survey

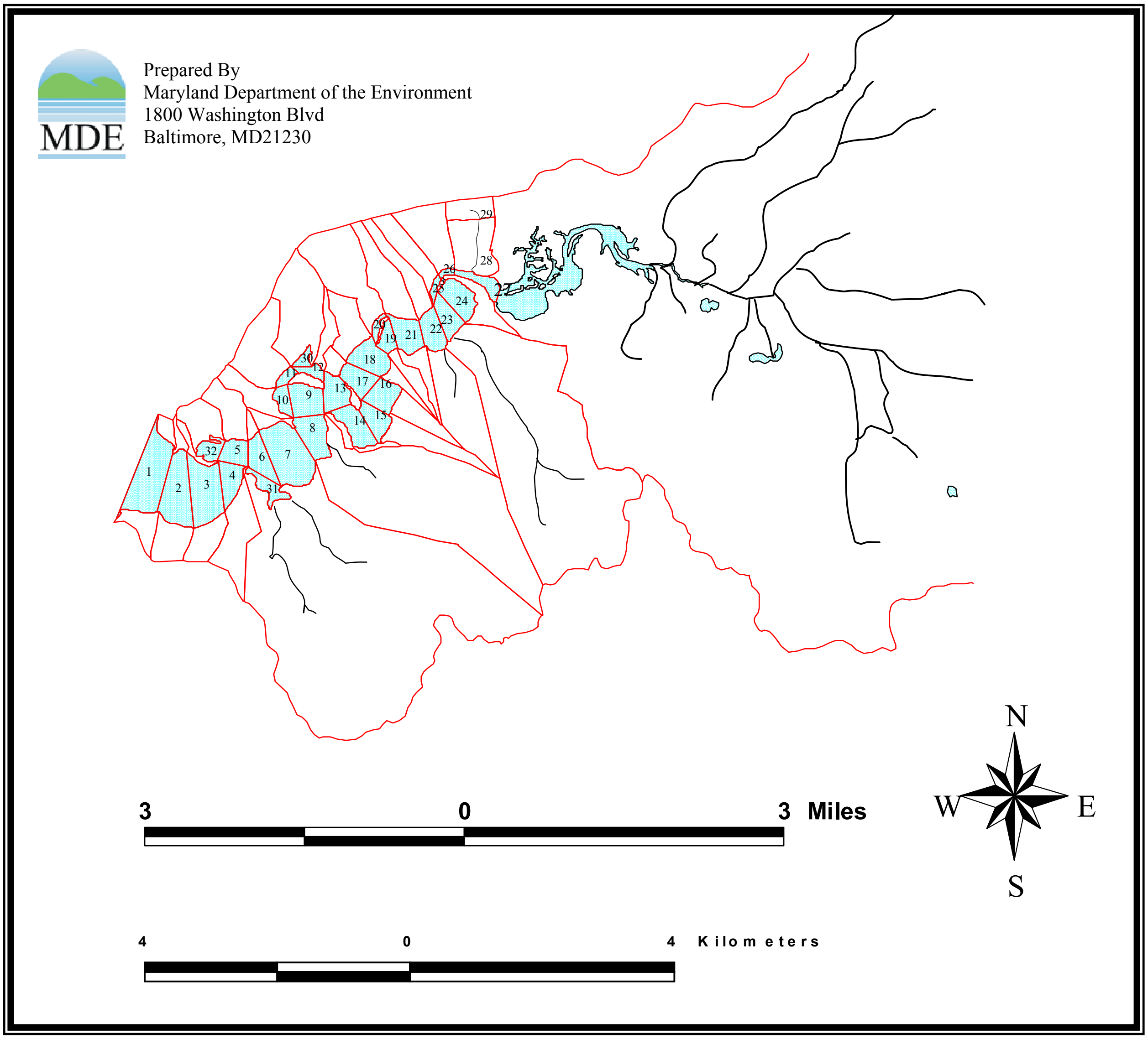


Figure A10. MCEM model segmentation and associated subwatersheds

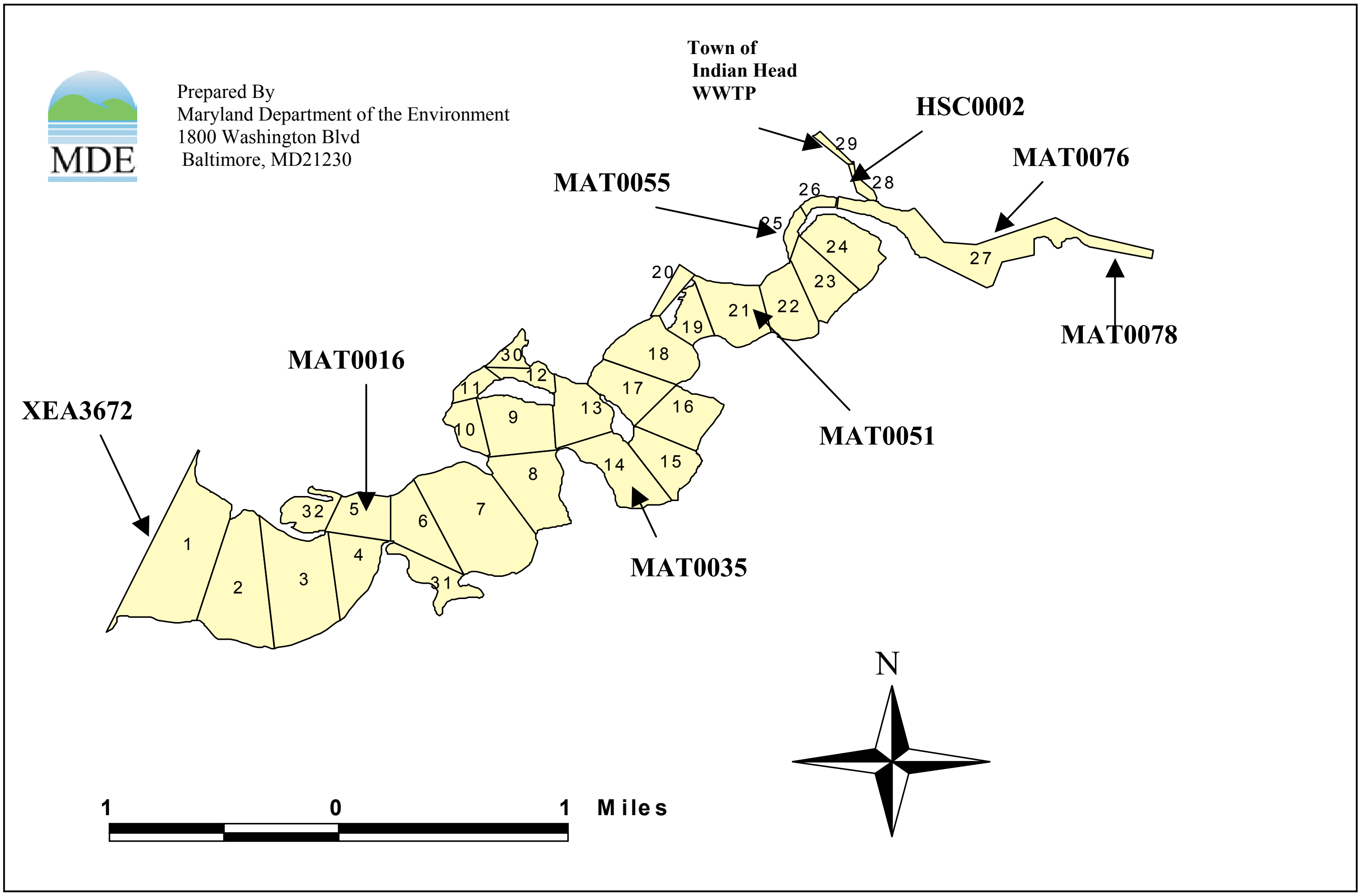


Figure A11: MCEM model segmentation and reference water quality stations

Low Flow Calibration

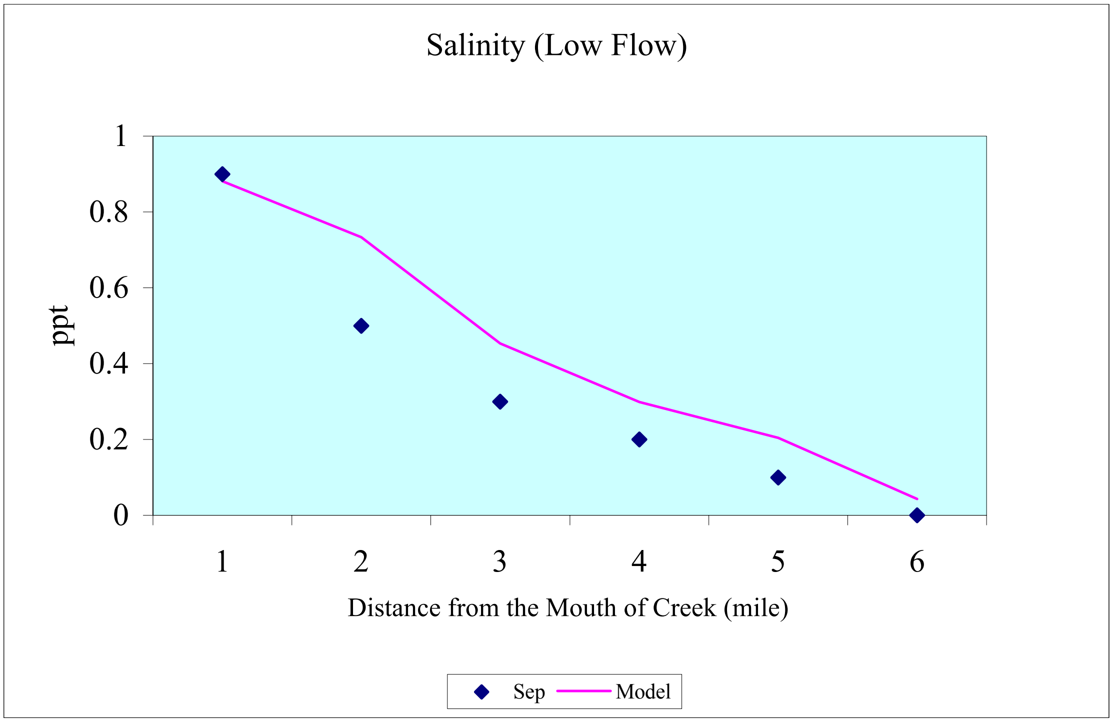


Figure A12: Salinity profile for the calibration of dispersion coefficients using 2001 Mattawoman Creek water quality survey data

Low Flow Calibration

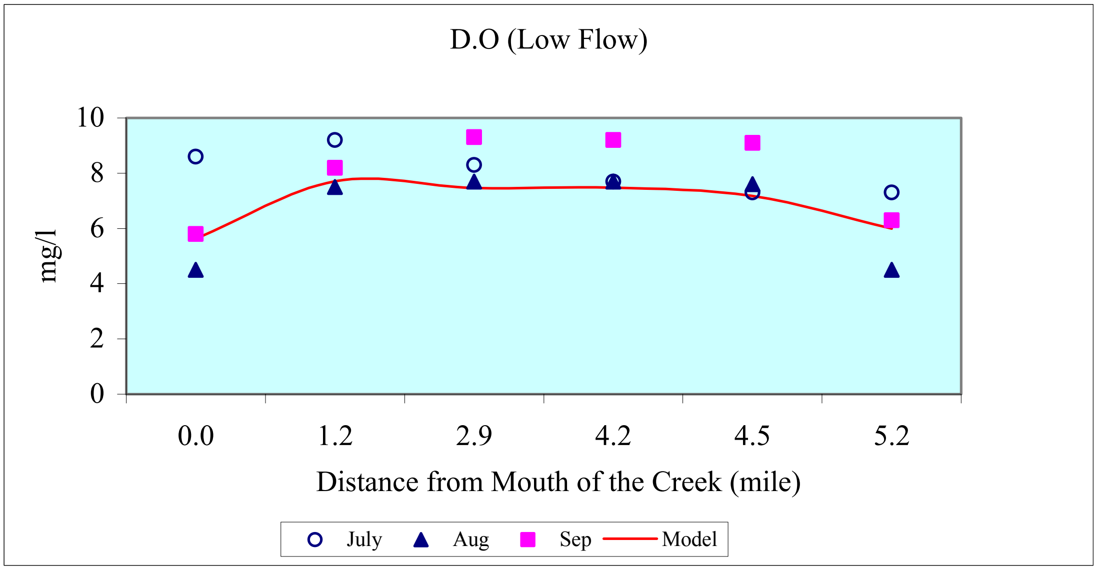


Figure A13 : DO profile for the calibration of dissolved oxygen for MCEM using Mattawoman Creek survey data from 2001 low flow period

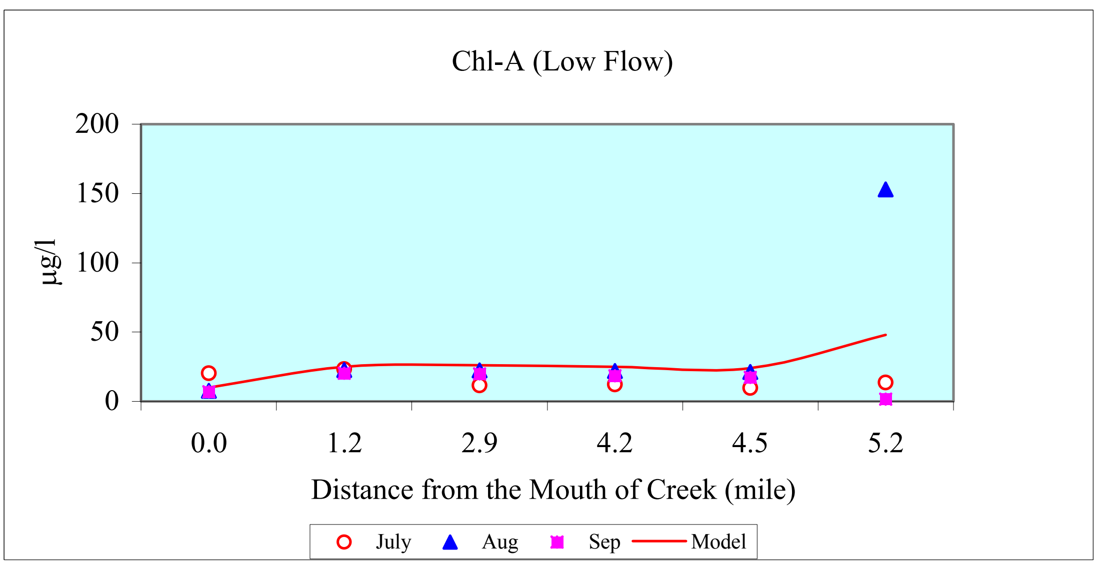


Figure A14 : Chlorophyll profile for the calibration of Chlorophyll *a* for MCEM using Mattawoman Creek survey data from 2001 low flow period.

Low Flow Calibration

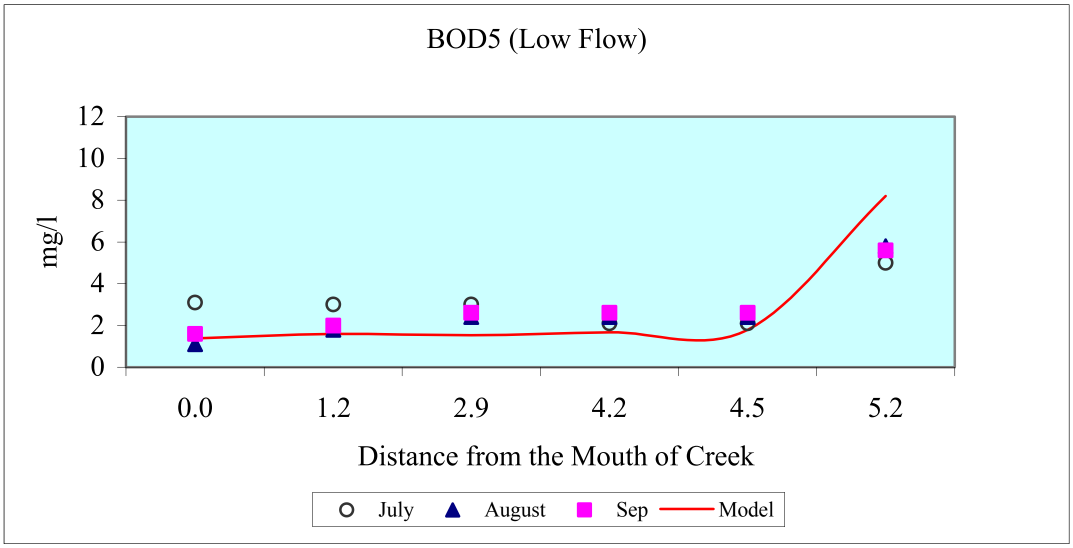


Figure A15 : BOD_5 vs. River Mile for the calibration of BOD_5 for MCEM using Mattawoman Creek survey data from 2001 low flow period

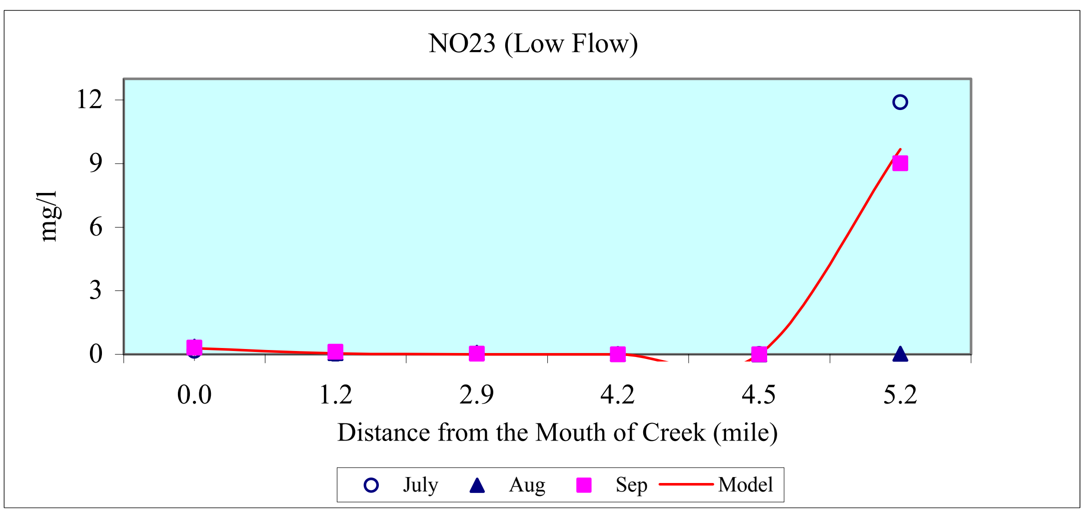


Figure A16 : NO_{23} vs. River Mile for the calibration of NO_{23} for MCEM using Mattawoman Creek survey data from 2001 low flow period.

Low Flow Calibration

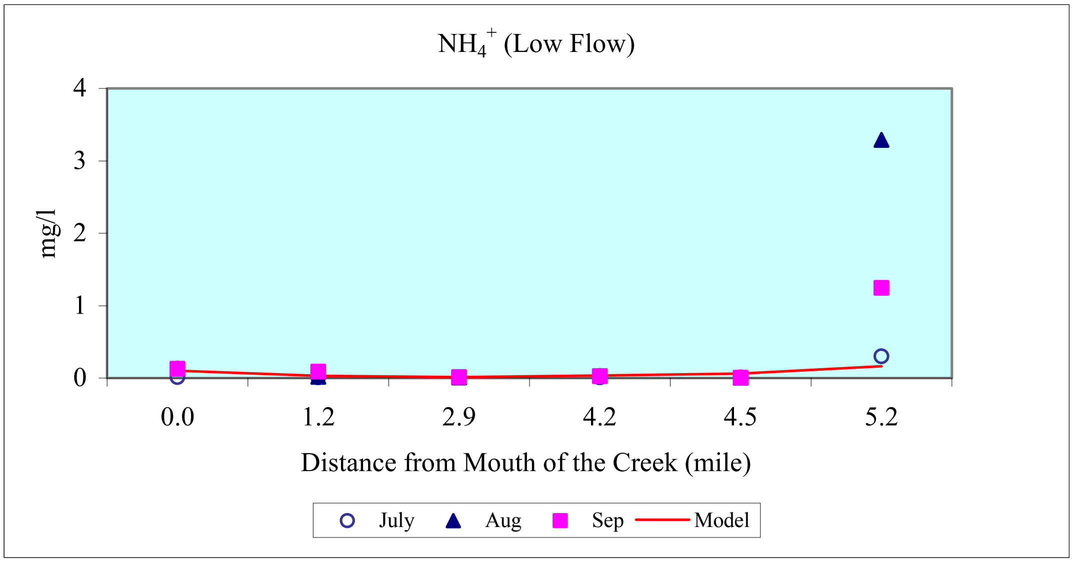


Figure A17 : NH_3 vs. River Mile for the calibration of NH_3 for MCEM using Mattawoman Creek survey data from 2001

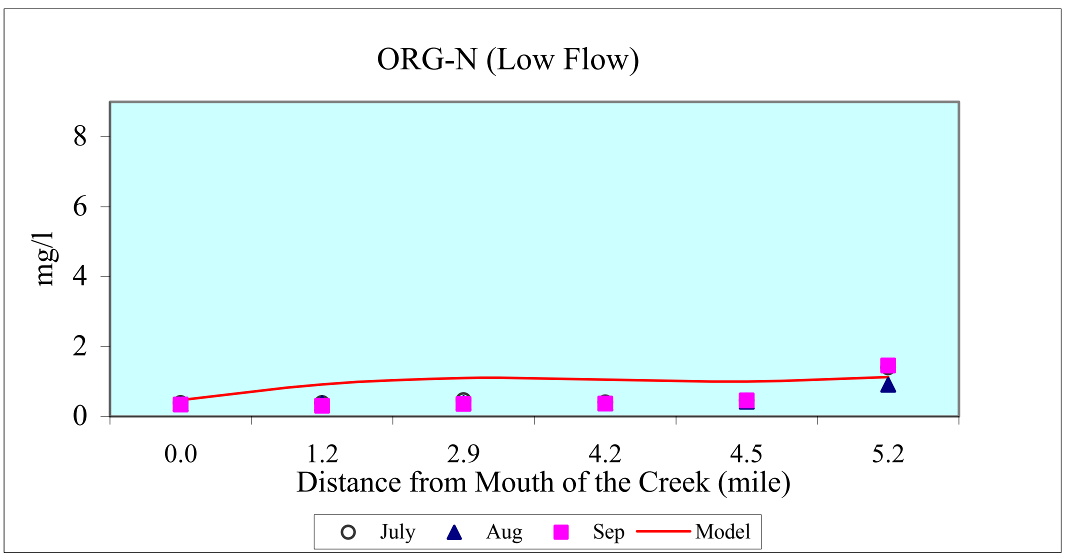


Figure A18 : Total Organic Nitrogen vs. River Mile for the calibration of Total Organic Nitrogen for MCEM using Mattawoman Creek survey data from 2001

Low Flow Calibration

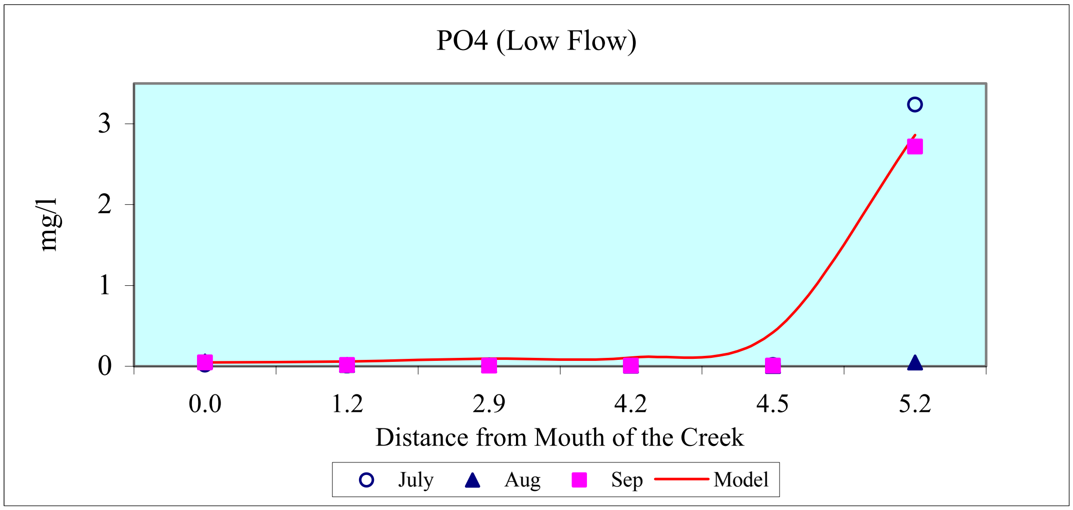


Figure A19 : PO_4 vs. River Mile for the calibration of PO_4 for MCEM using Mattawoman Creek survey data from 2001.

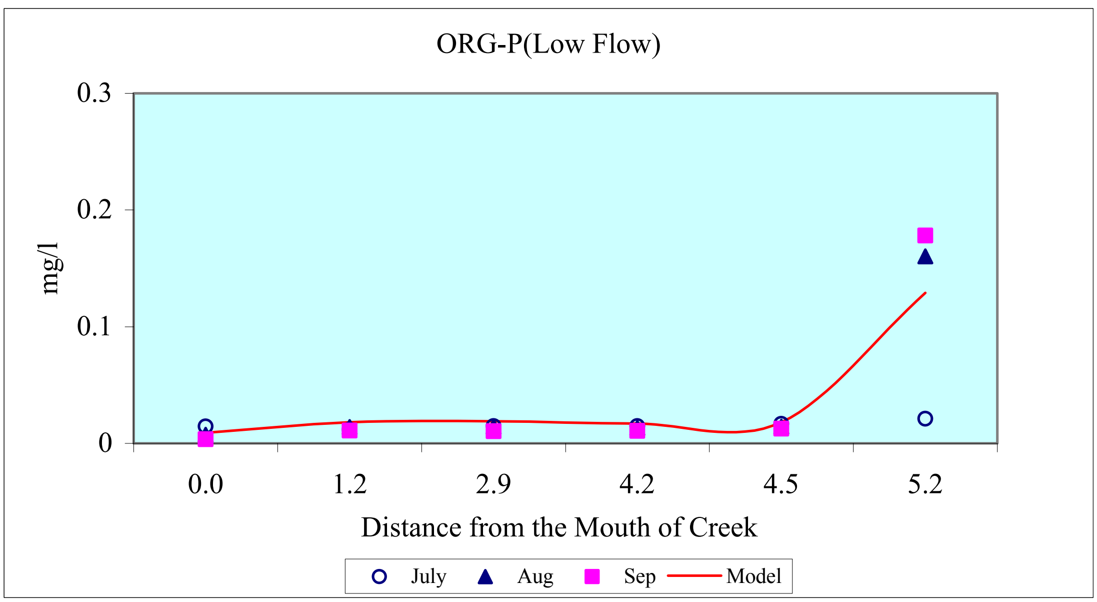


Figure A20 : Total Organic Phosphorus vs. River Mile for the calibration of Organic Phosphorus for MCEM using Mattawoman Creek survey 2001 Data.

Low Flow Baseline

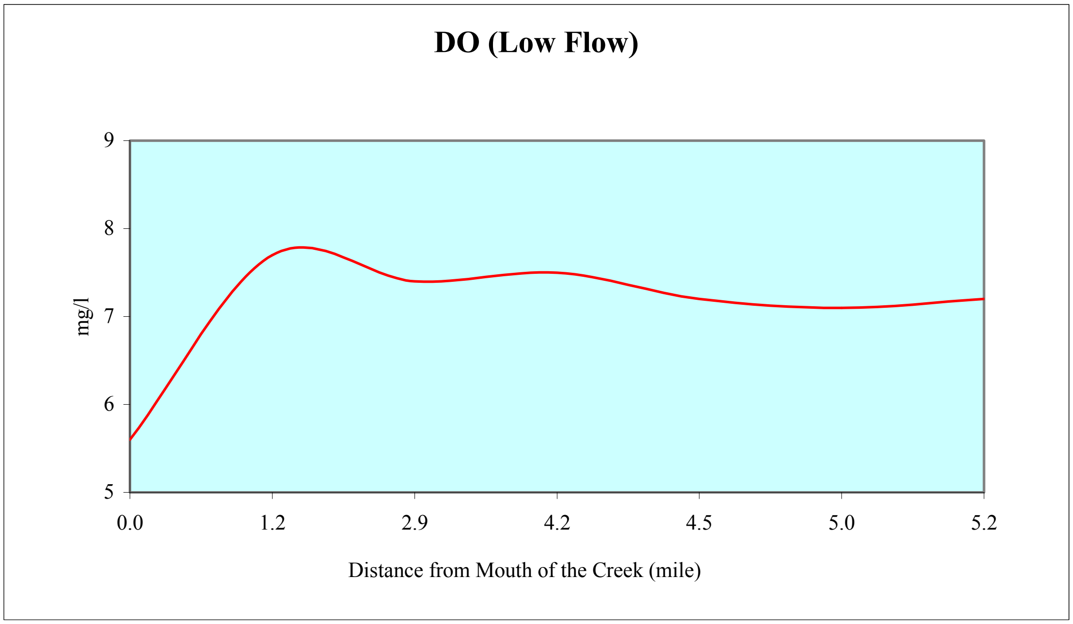


Figure A21: DO profile for MCEM low flow baseline condition

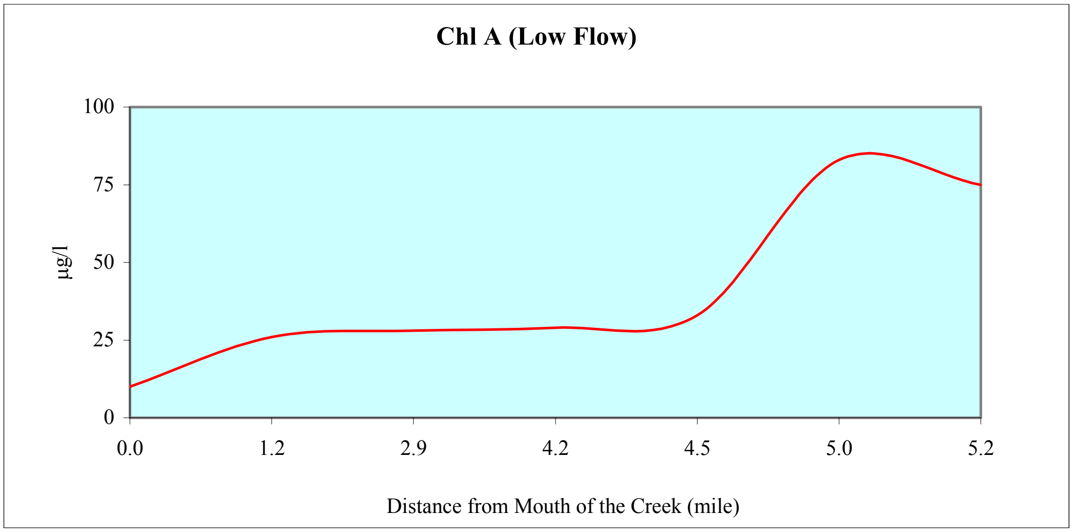


Figure A22: Chlorophyll profile for MCEM low flow baseline condition

Low Flow Baseline

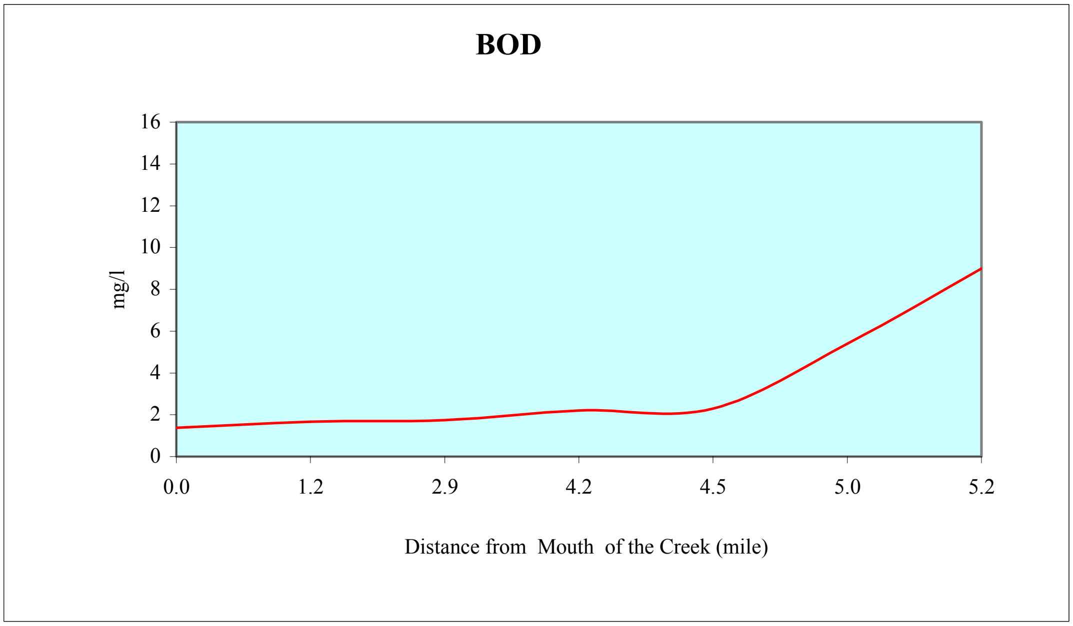


Figure A23: BOD_5 profile for MCEM low flow baseline condition

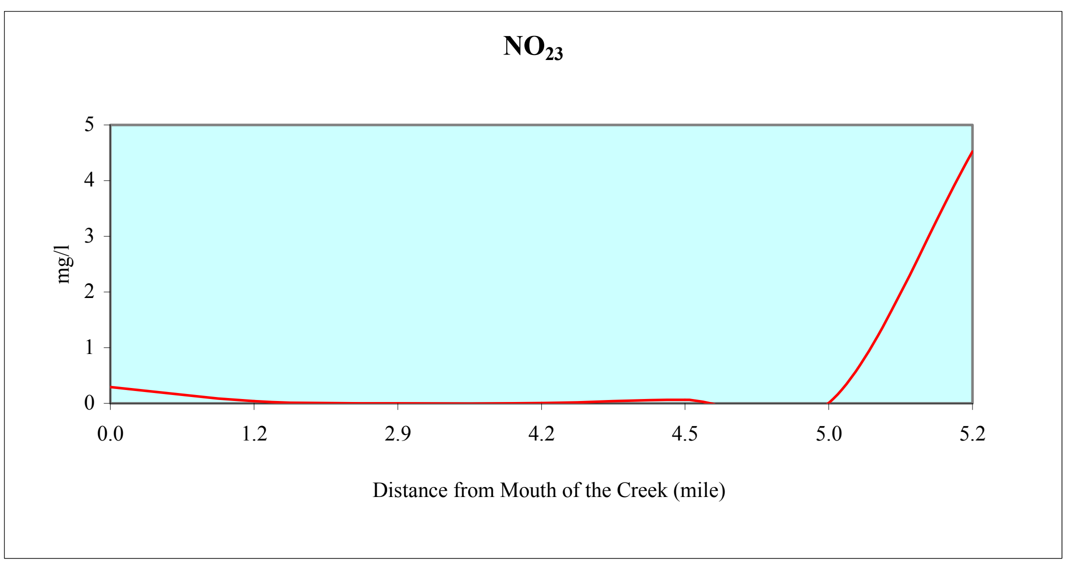


Figure A24: NO_{23} profile for MCEM low flow baseline condition

Low Flow Baseline

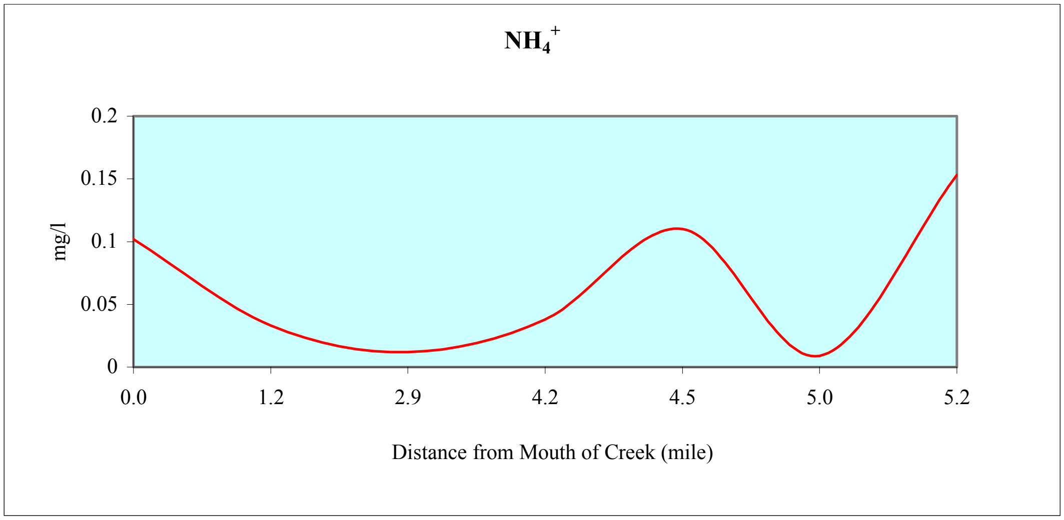


Figure A25: NH_4 profile for MCEM low flow baseline condition

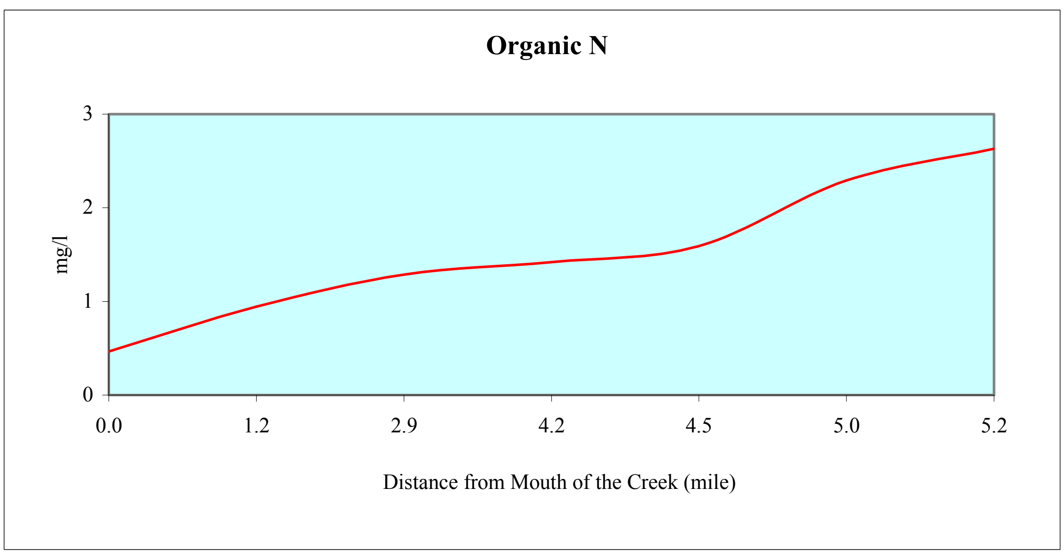


Figure A26: Organic Nitrogen profile for MCEM low flow baseline condition

Low Flow Baseline

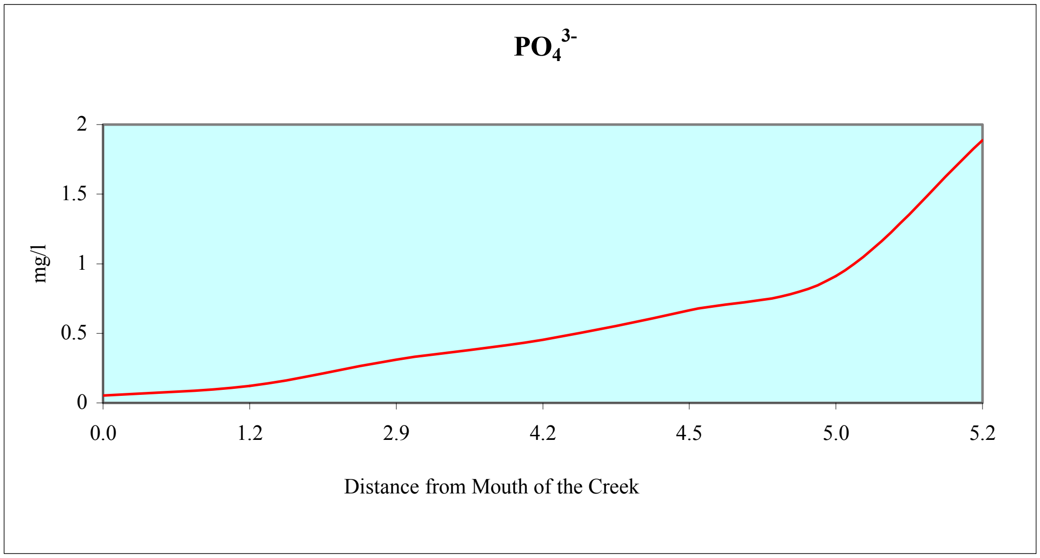


Figure A27: PO_4 profile for MCEM low flow baseline condition

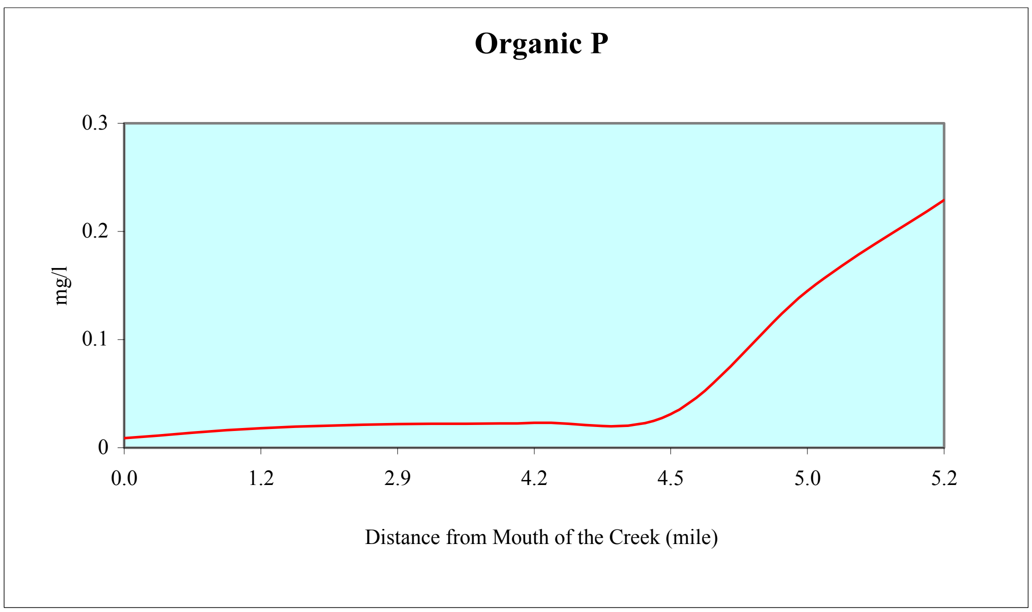


Figure A28: Organic phosphorus profile for MCEM low flow baseline condition

Low Flow TMDL

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

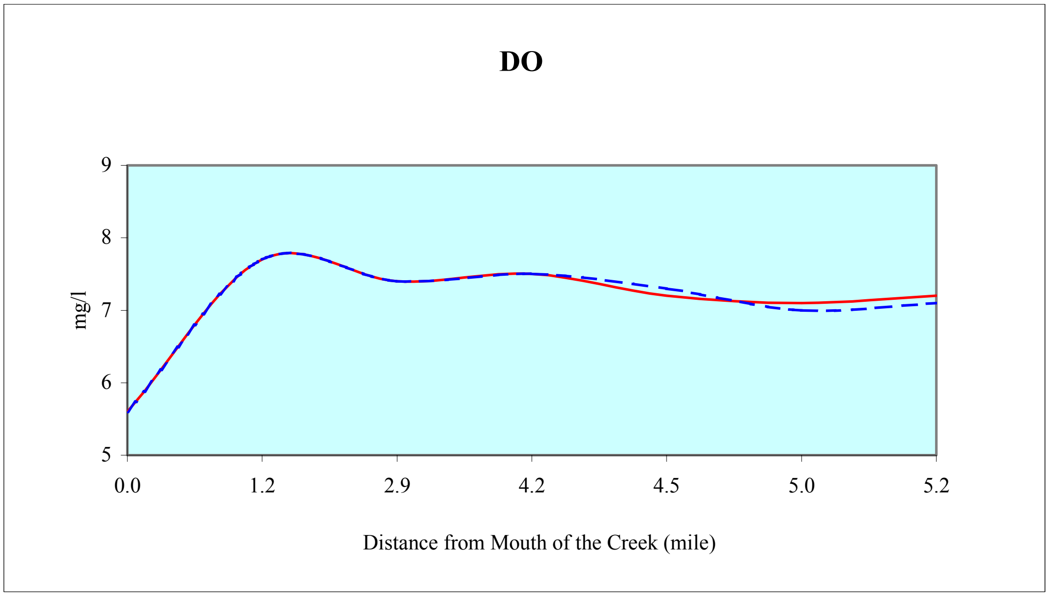


Figure A29 : DO profile for MCEM TMDL (dash line)

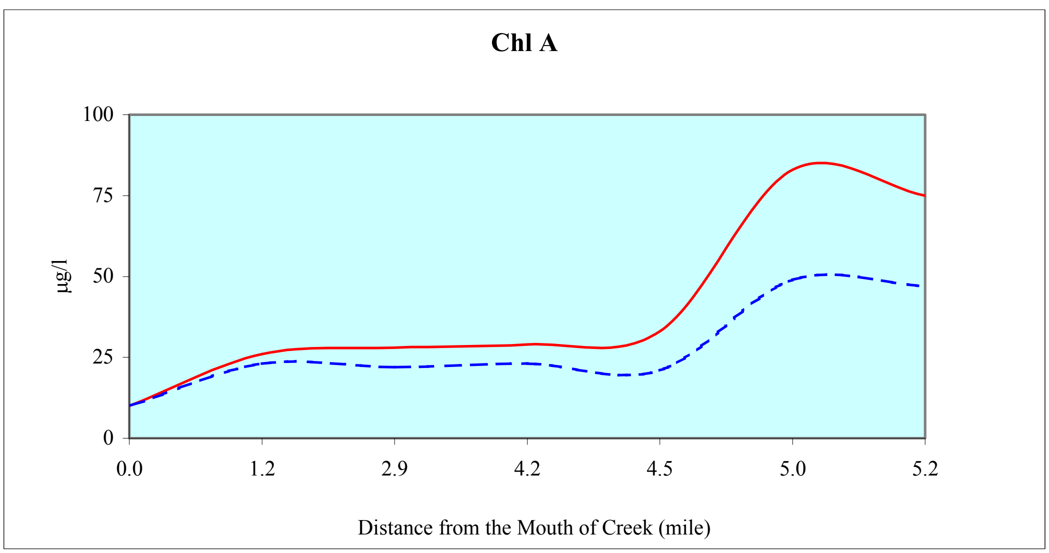


Figure A30: Chlorophyll a profile for MCEM TMDL (dash line)

Low Flow TMDL

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

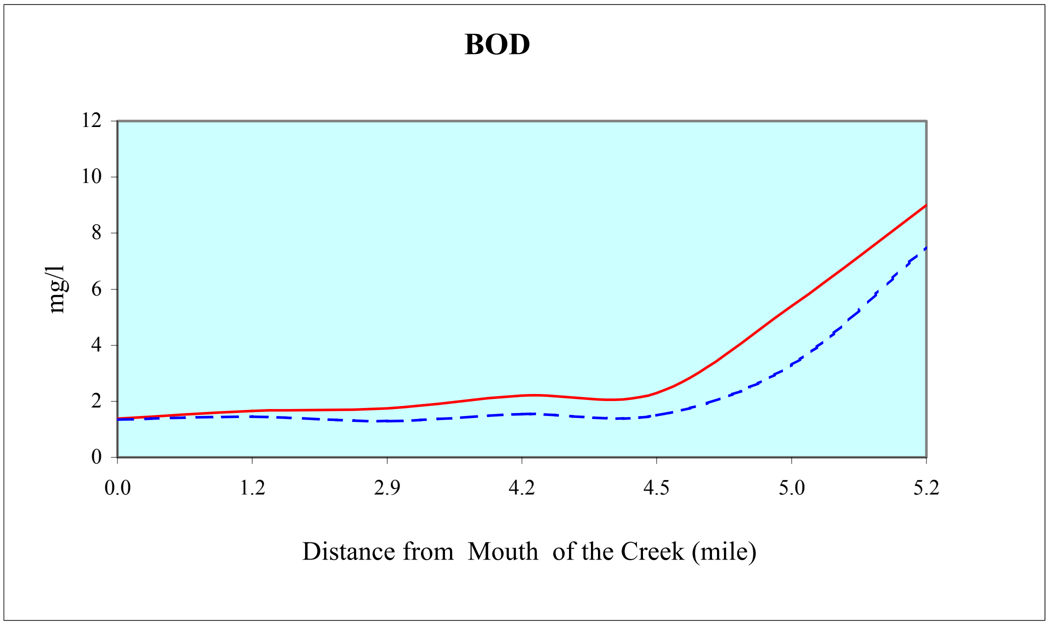


Figure A31: BOD_5 profile for MCEM TMDL (dash line)

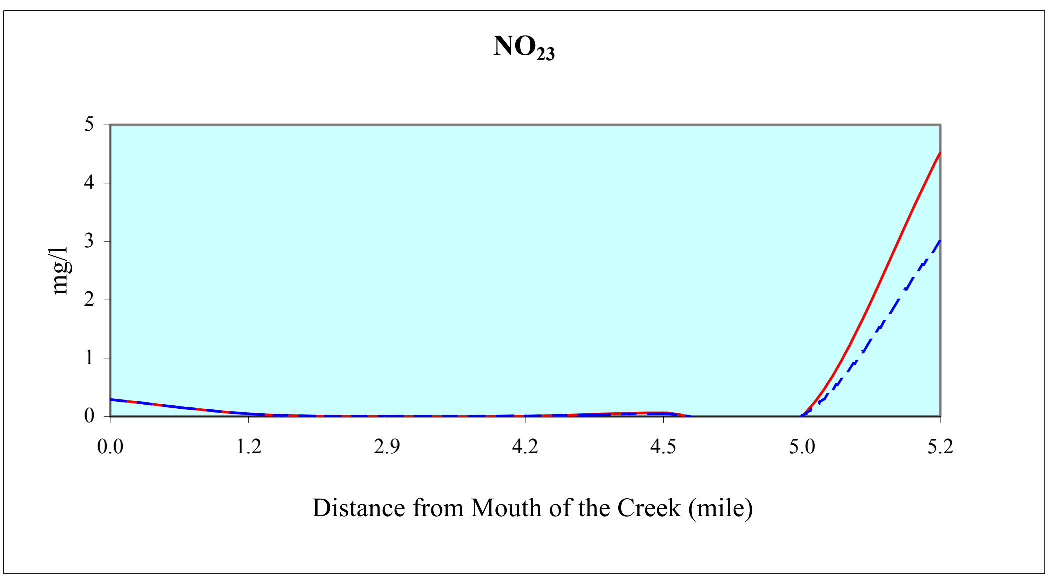


Figure A32: NO_{23} profile for MCEM TMDL (dash line)

Low Flow TMDL

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

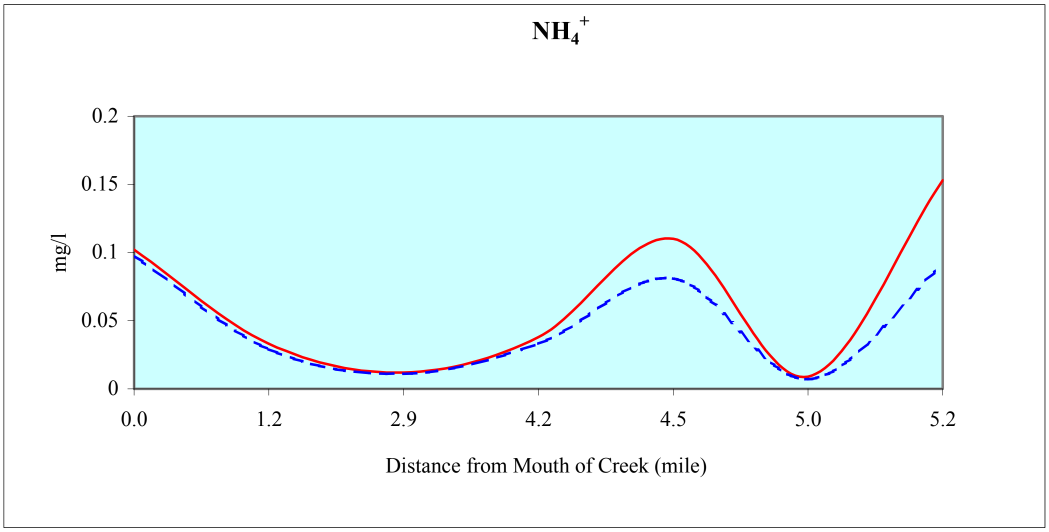


Figure A33: NH_4 profile for MCEM TMDL (dash line)

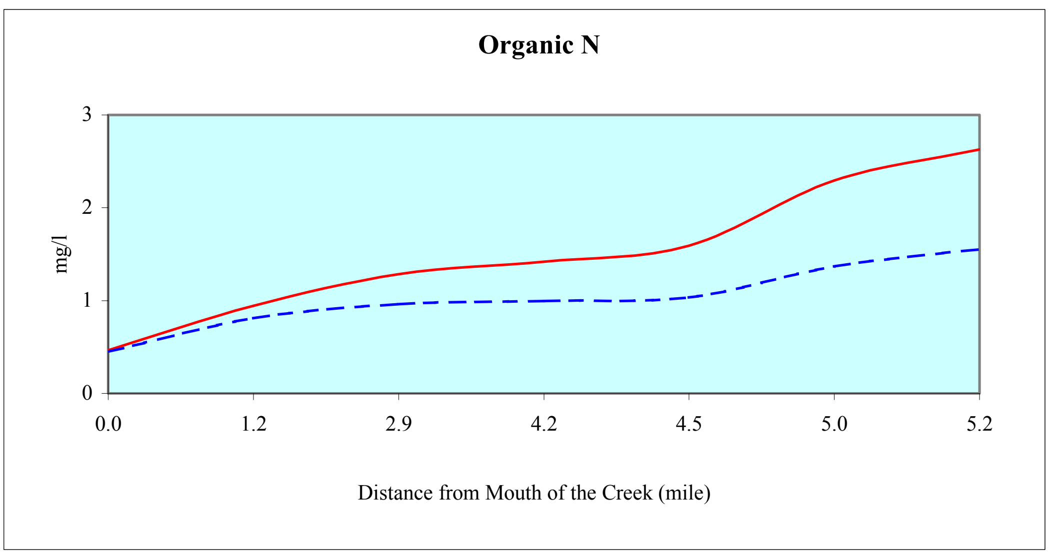


Figure A34: Organic Nitrogen profile for MCEM TMDL (dash line)

Low Flow TMDL

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

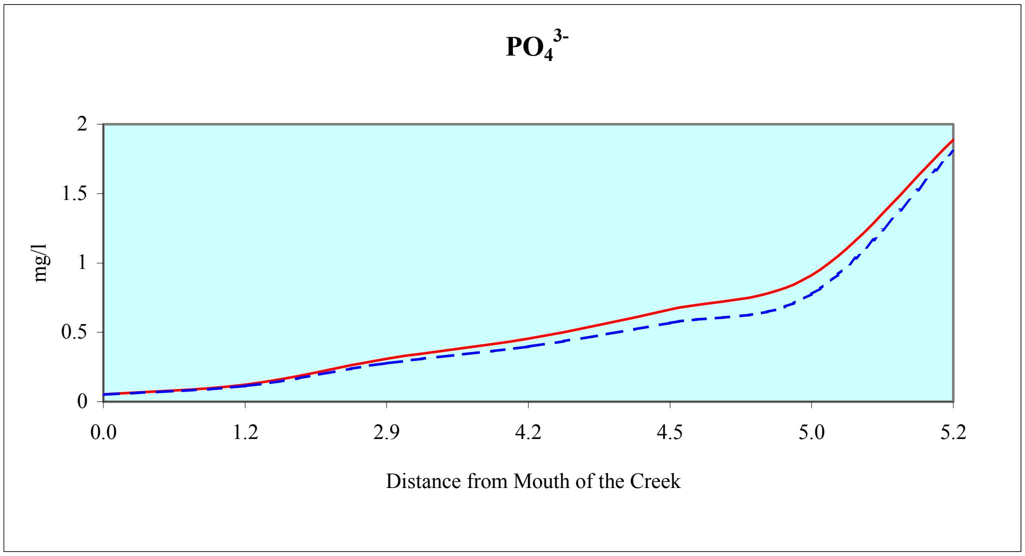


Figure A35: PO_4^{3-} profile for MCEM TMDL (dash line)

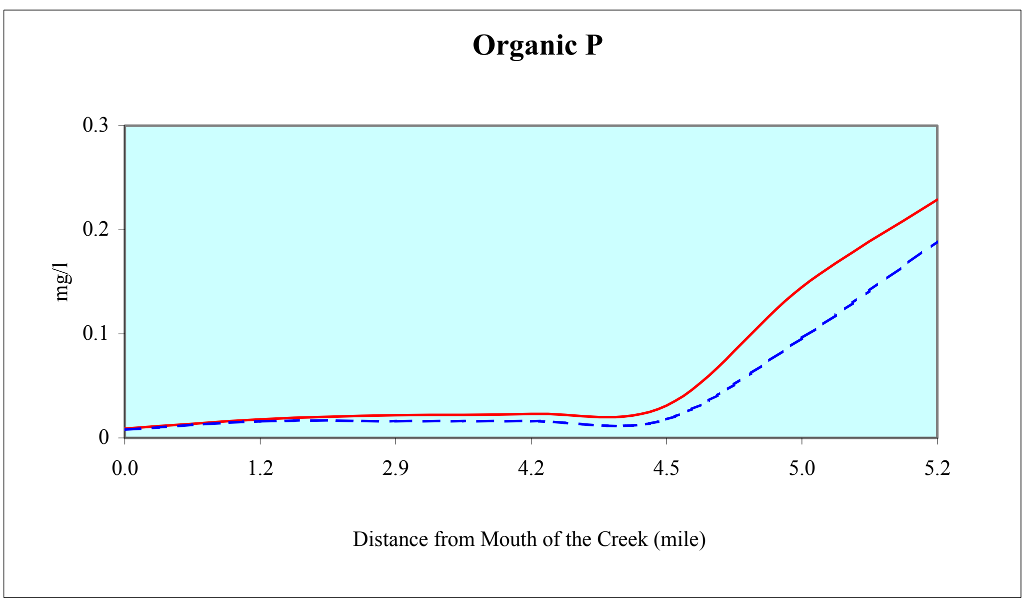


Figure A36: Organic Phosphorus profile for MCEM TMDL (dash line)

Average Annual Flow Baseline

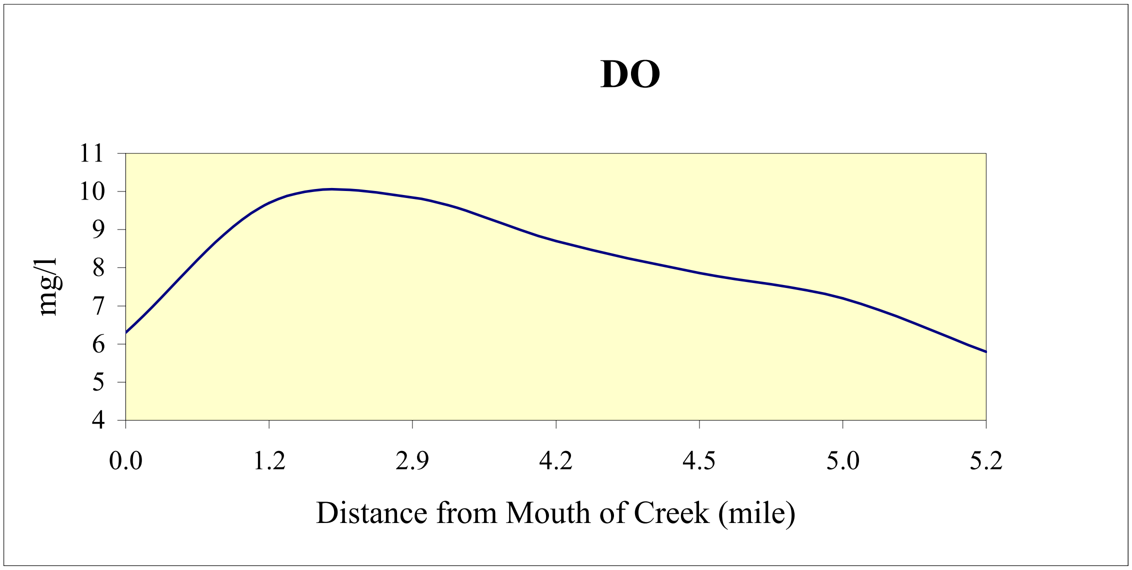


Figure A37: DO profile for MCEM Average Annual Flow Baseline Condition

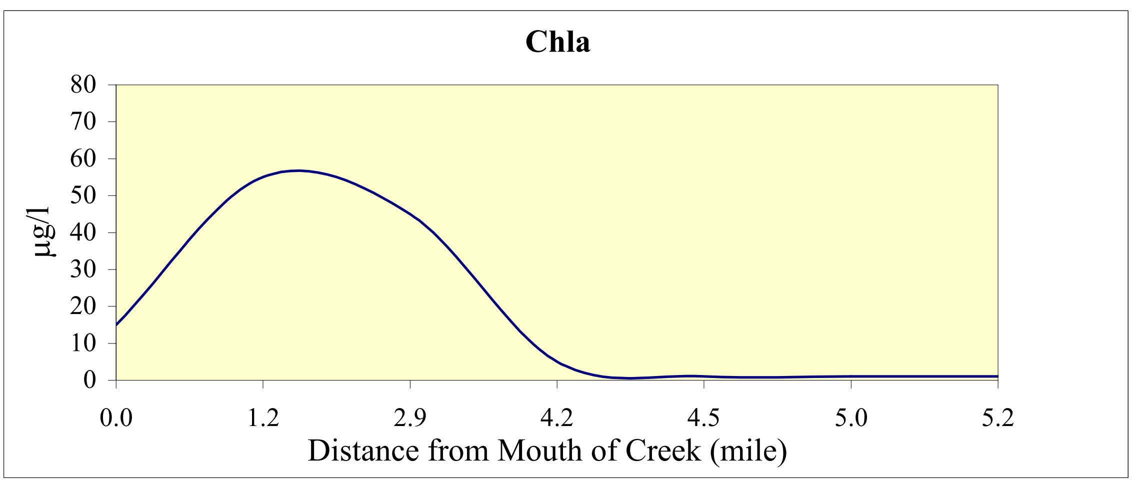


Figure A38: Chlorophyll *a* profile for MCEM Average Annual Flow Baseline Condition

Average Annual Flow Baseline

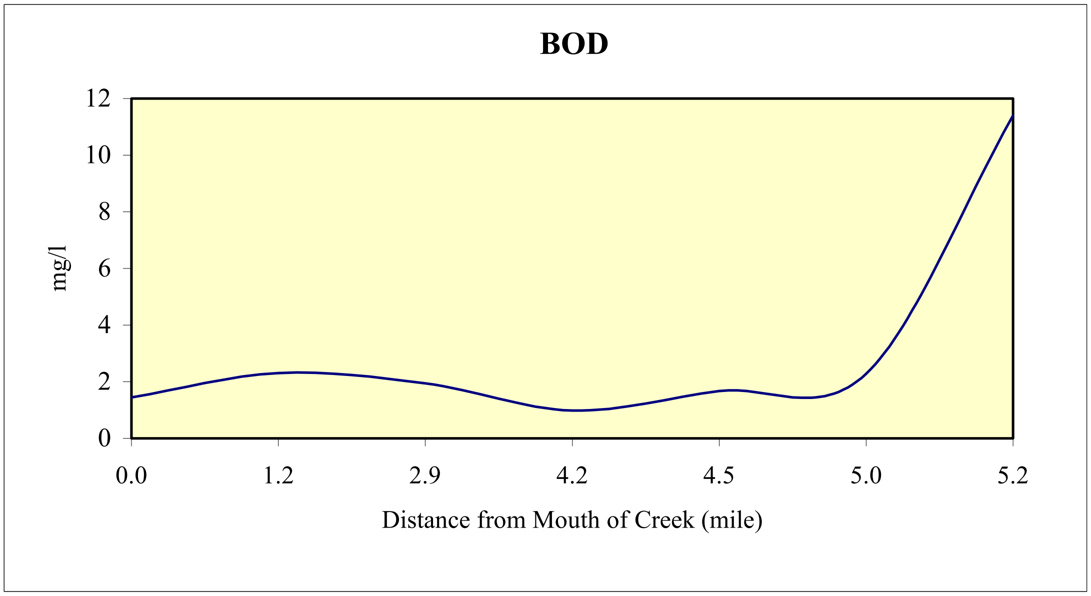


Figure A39: BOD_5 profile for MCEM Average Annual Flow Baseline Condition

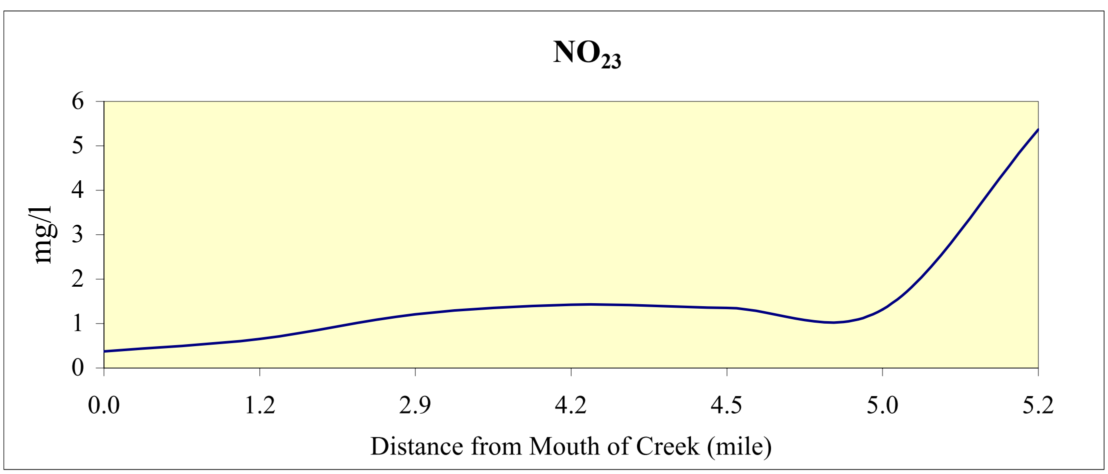


Figure A40: NO23 profile for MCEM Average Annual Flow Baseline Condition

Average Annual Flow Baseline

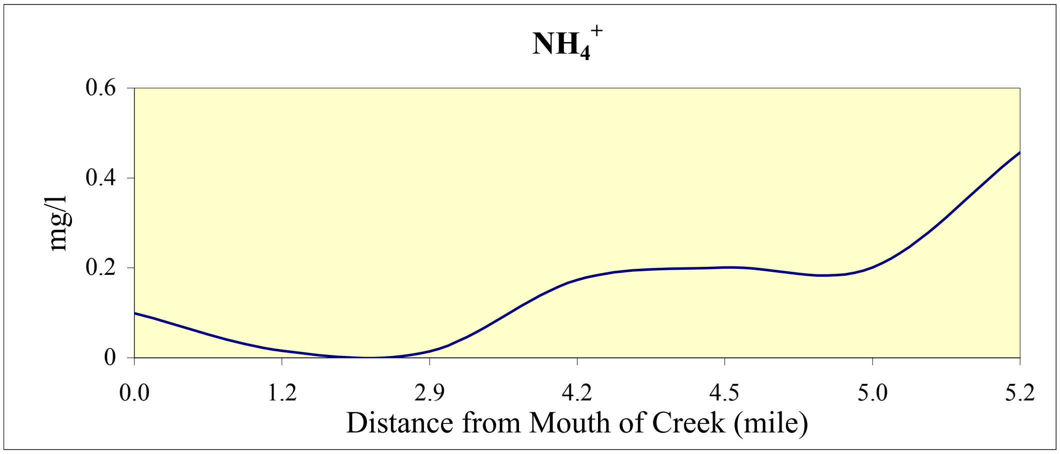


Figure A41: NH_4^+ profile for MCEM Average Annual Flow Baseline Condition

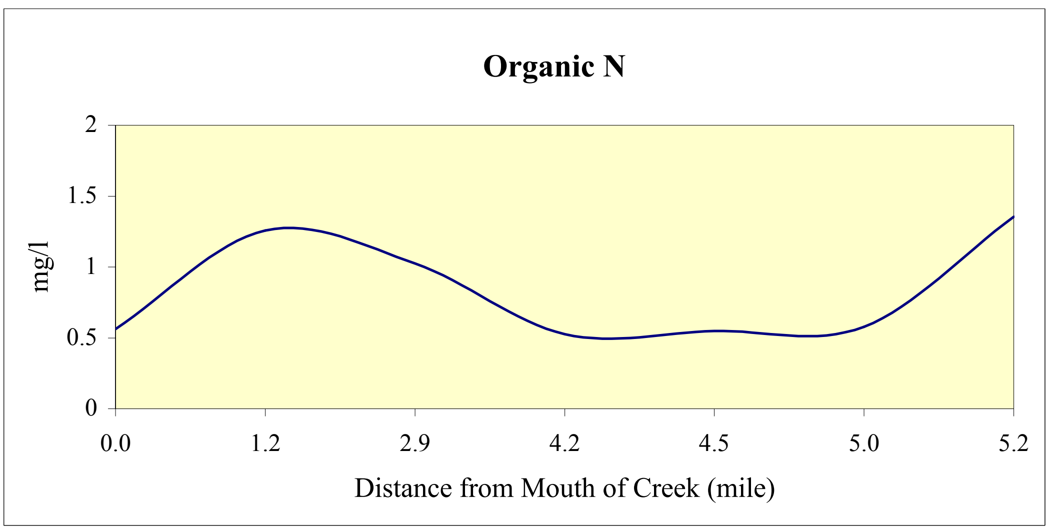


Figure A42: Organic Nitrogen profile for MCEM Average Annual Flow Baseline Condition

Average Annual Flow Baseline

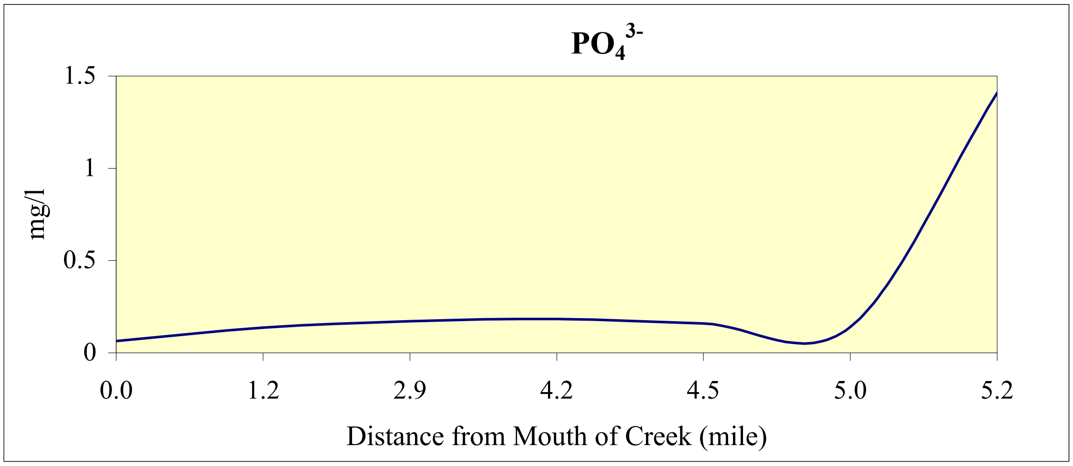


Figure A43: PO_4^{3-} profile for MCEM Average Annual Flow Baseline Condition

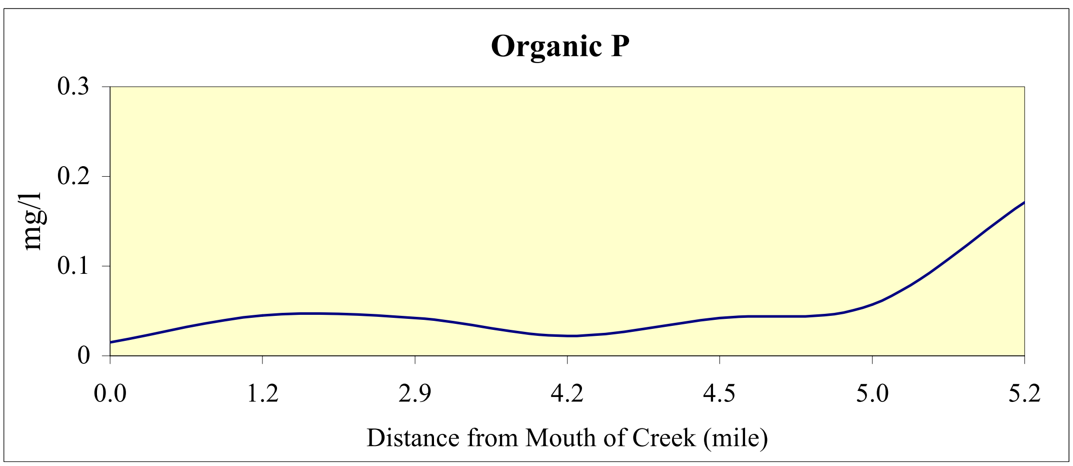


Figure A44: Organic Phosphorus profile for MCEM Average Annual Flow Baseline Condition

Average Annual Flow TMDL

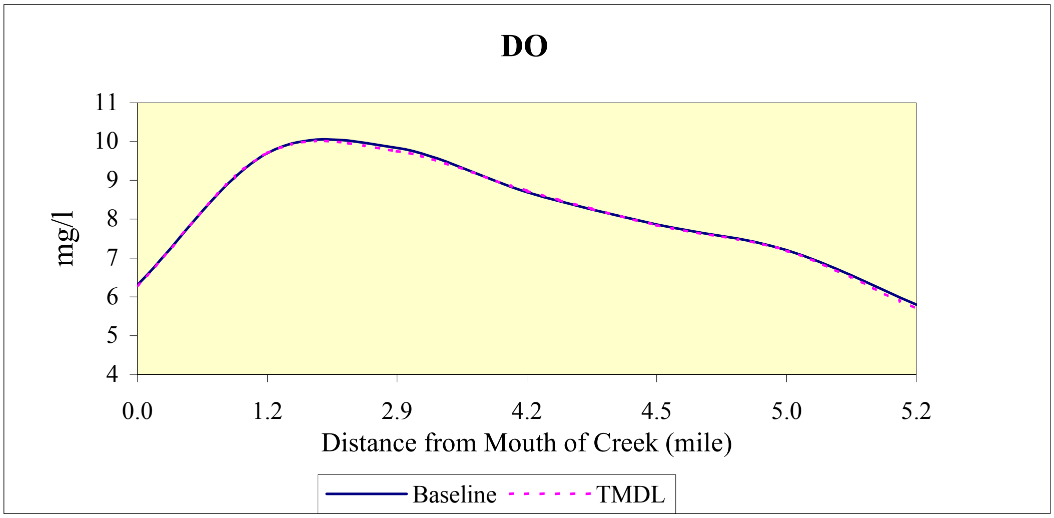


Figure A45: **Dissolved Oxygen profile for MCEM Average Annual Flow TMDL**

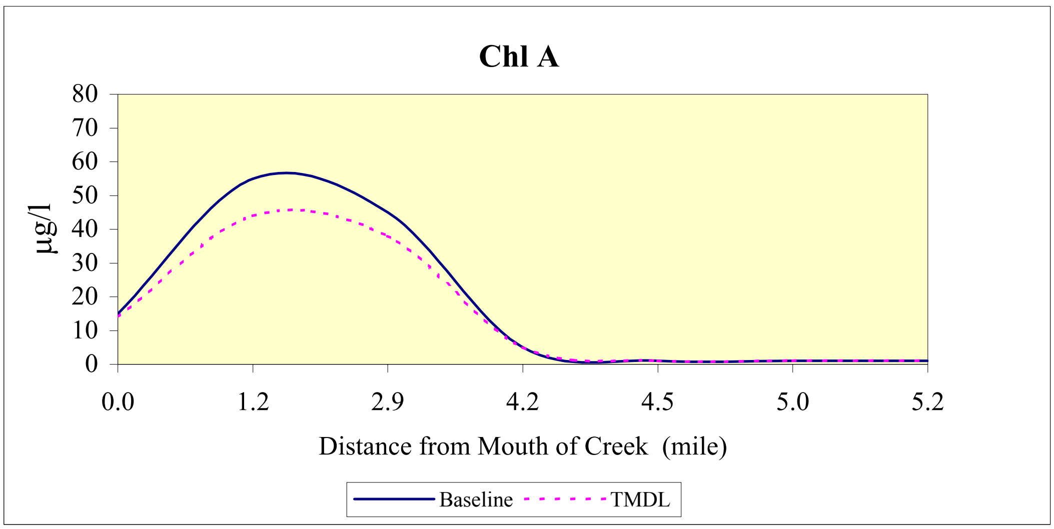


Figure A46: Chlorophyll *a* profile for MCEM Average Annual Flow TMDL

Average Annual Flow TMDL

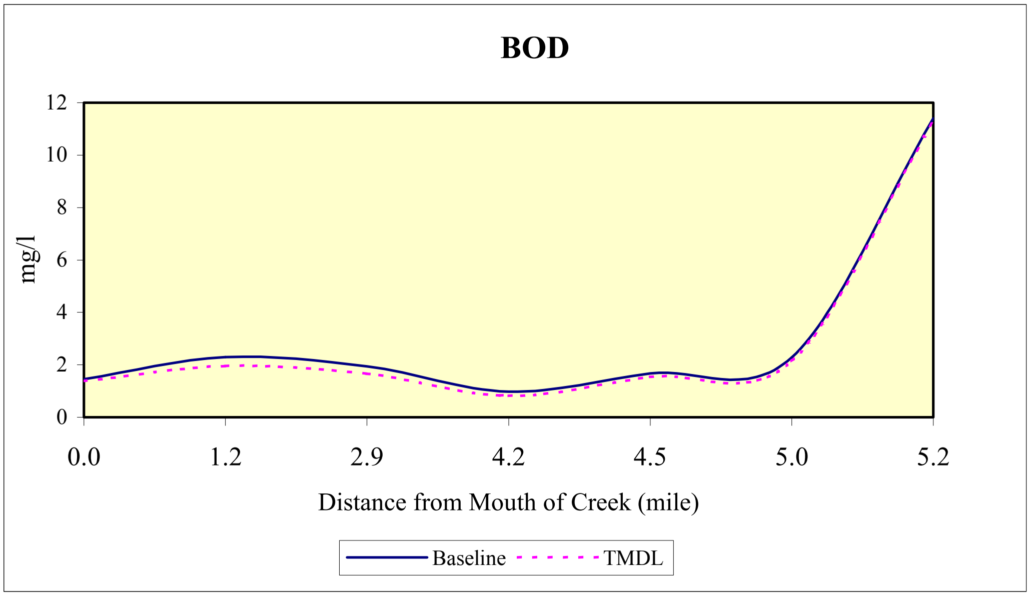


Figure A47: BOD profile for MCEM Average Annual Flow TMDL

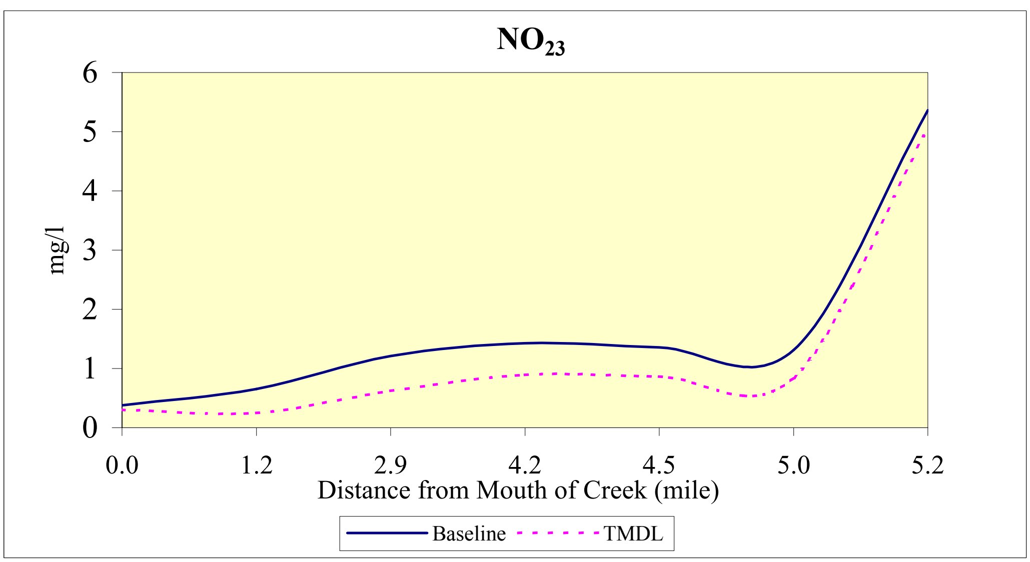


Figure A48: NO_{23} profile for MCEM Average Annual Flow TMDL

Average Annual Flow TMDL

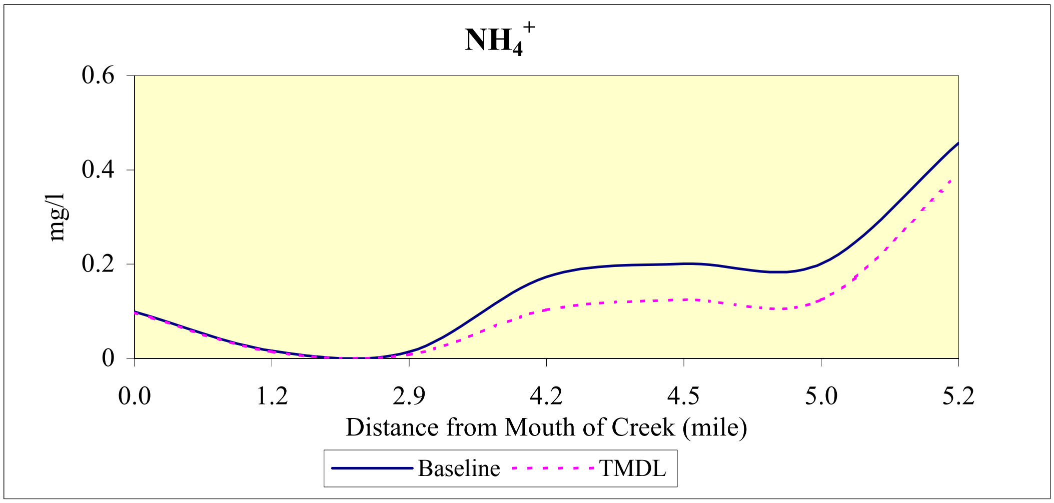


Figure A49: NH_4^+ profile for MCEM Average Annual Flow TMDL

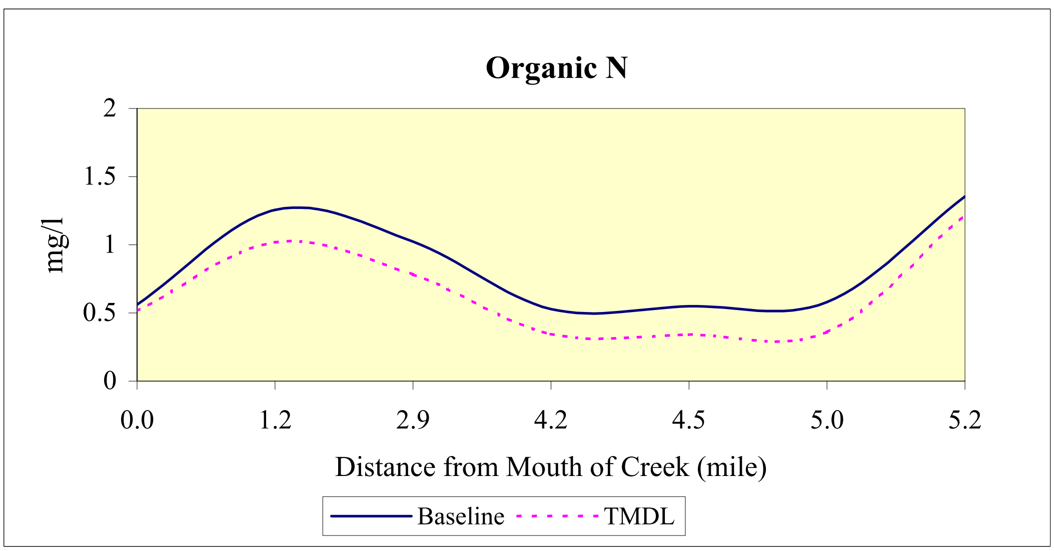


Figure A50: Organic N profile for MCEM Average Annual Flow TMDL

Average Annual Flow TMDL

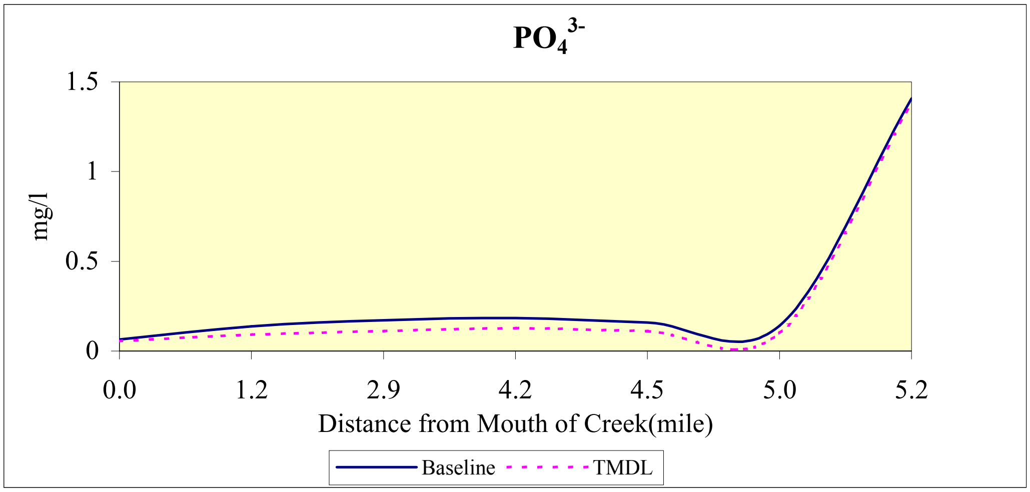


Figure A51: PO_4^{3-} vs. profile for MCEM Average Annual Flow TMDL

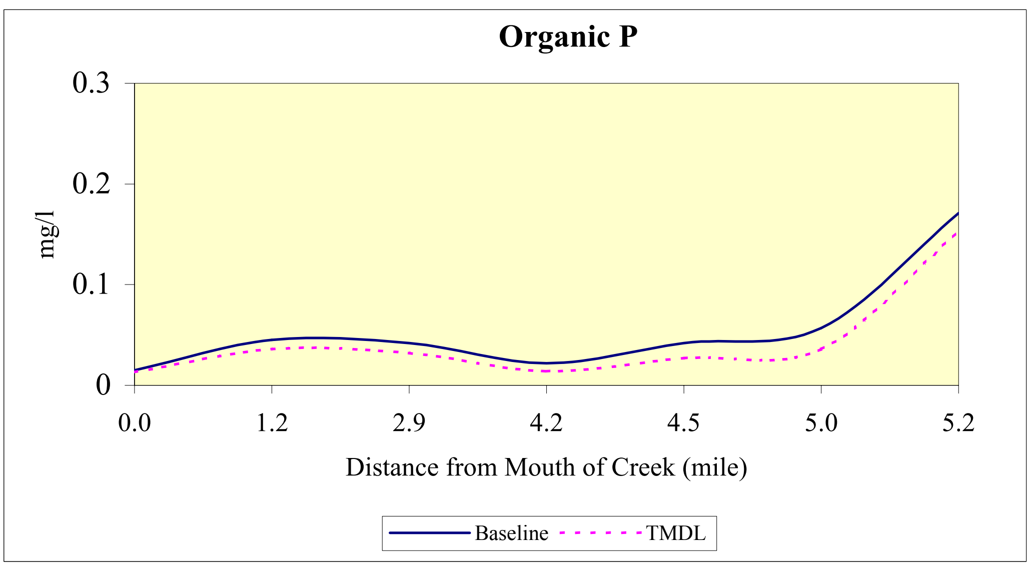


Figure A52: Organic P profile for MCEM Average Annual Flow TMDL

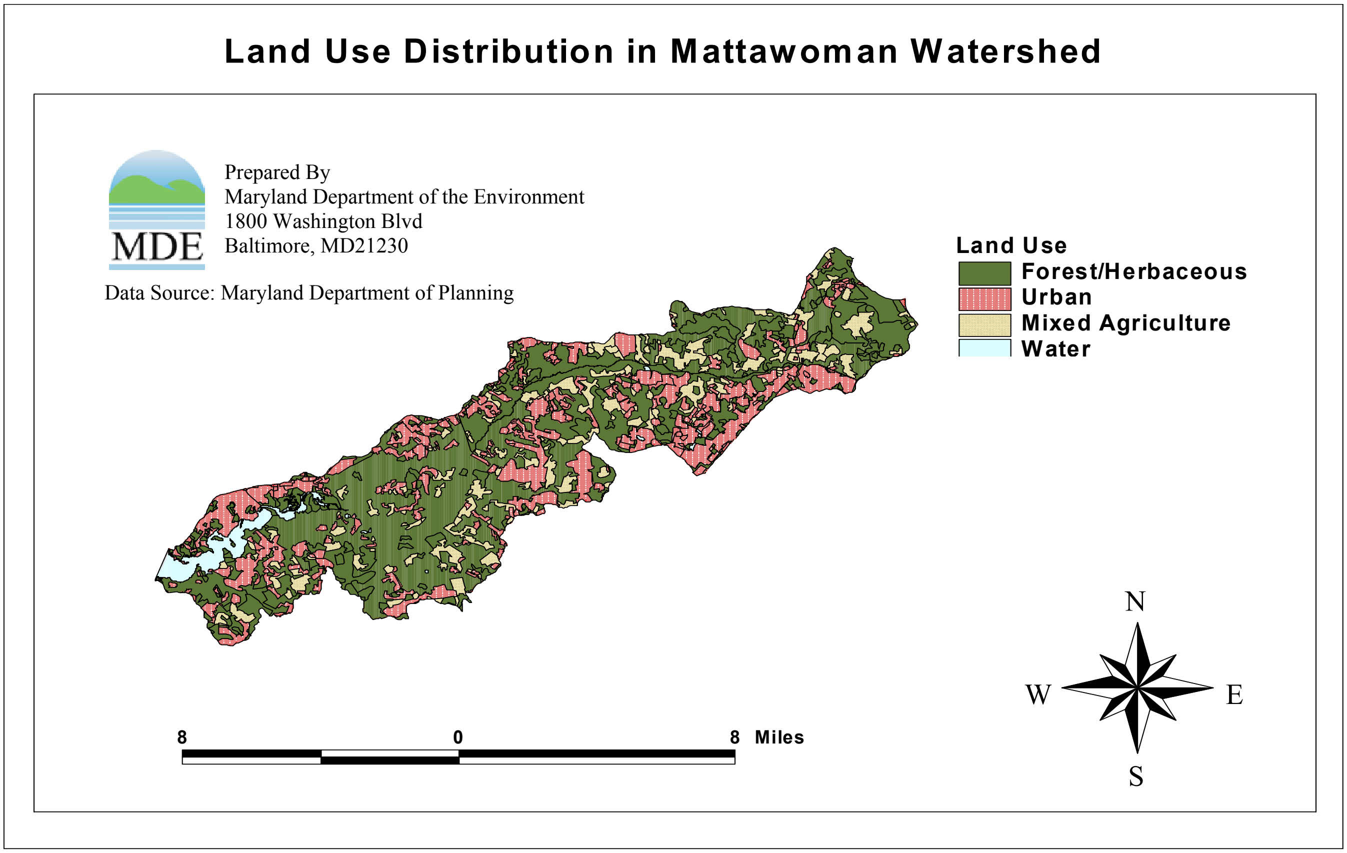
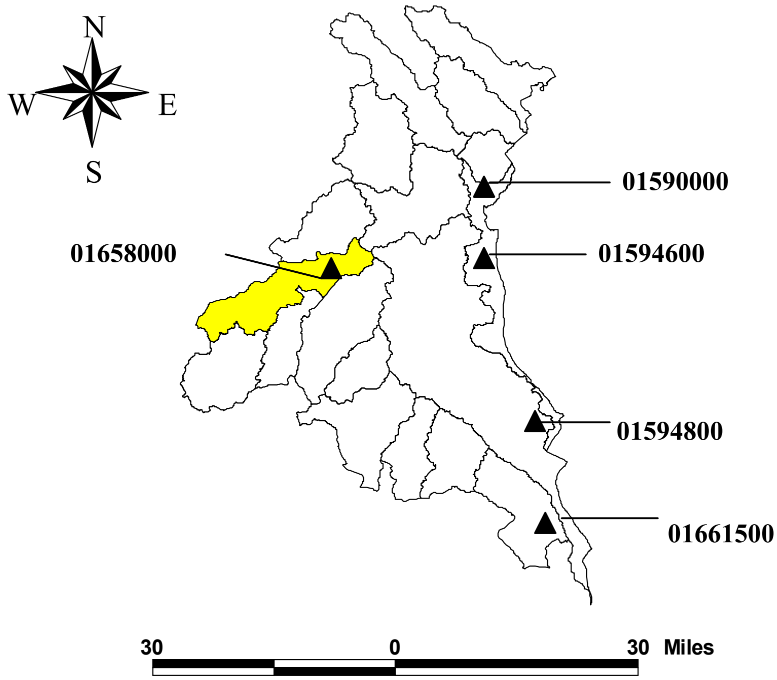


Figure A53: Land Use in Mattawoman Creek Watershed



MDE

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Figure A54. USGS gaging stations from Southern Maryland Hydrological region selected for flow estimation in MCEM (shaded area indicates Mattawoman Creek Watershed)

Calculation of the Estimated changes in Nutrient Loadings due to Land Use (LU) Changes Over a 6-year Time Span (1994-2000)

Estimation for nutrient loading gain on Mattawoman Watershed due to LU conversion (LU based on 1994 and 2000 MDP data)

		avg. annual gain/loss
Urban LU : Increase from 13,576 acre to 16,036 acre	+2,460 acre	***+410 acre/yr***
Forest LU: Decrease from 37,722 acre to 36,614 acre	-1608 acre	**-268 acre/yr**
Agriculture LU: Decrease from 8,134 acre to 7,282 acre	-852 acre	**-142 acre/yr**

nutrient loading coefficients (based on CBP V.4.3) **After TMDL adjustment**

	N (lbs/acre/yr)	P (lbs/acre/yr)	N (lbs/acre/yr)	P (lbs/acre/yr)
Urban	8.3	0.82	$8.3 \cdot 0.46 = 3.818$	$0.82 \cdot 0.53 = 0.435$
Agriculture	14	0.83	$14 \cdot 0.46 = 6.44$	$0.83 \cdot 0.51 = 0.423$
Forest	1.3	0.02	1.3	0.02

Based on 54% reduction for urban and agri for N
47% for urban and 49% for agri for P

now apply the adjusted loading coefficients to calculate the anuual nutrient gained due to LU conversion

for nitrogen : **303** lbs/yr (compared to the FA for Nitrogen in Mattawoman TMDL : **9,689** lbs/yr)

$$410 \cdot 3.82 - 268 \cdot 1.3 - 142 \cdot 6.44 = 303.32 \frac{lbs}{yr}$$

for phosphorus : **113** lbs/yr (compared to the FA for Phosphorus in Mattawoman TMDL : **673** lbs/yr)

$$410 \cdot 0.435 - 268 \cdot 0.02 - 142 \cdot 0.423 = 112.924 \frac{lbs}{yr}$$

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