APPENDIX A

Total Maximum Daily Loads of Nitrogen and Biochemical Oxygen Demand for the Manokin River, Somerset County, Maryland

Report Version: October 17, 2000

MODELING FRAMEWORK

The computational framework chosen for the modeling of water quality of the Manokin River was WASP5.1. This program provides a generalized framework for modeling contaminant fate and transport in surface waters (Di Toro *et al.*, 1983) and is based on the finite-segment approach. It is a very versatile program, capable of studying time-variable or steady-state, one, two or three dimensional, linear or non-linear kinetic water quality problems. To date, WASP5.1 has been employed in many modeling applications that have included river, lake, estuarine and ocean environments, and the model has been used to investigate dissolved oxygen, eutrophication, and toxic substance problems. WASP5.1 has been used in a wide range of applications by regulatory agencies, consulting firms, and others.

WASP5.1 is supported and distributed by U.S. EPA's Center for Exposure Assessment Modeling (CEAM) in Athens, GA (Ambrose *et al.*, 1993). EUTRO5.1 is the component of WASP5.1 that is applicable for modeling eutrophication, incorporating eight water quality constituents in the water column (Figure A1) and sediment bed. EUTRO5.1 is used to develop the water quality model of Manokin River system.

WATER QUALITY MONITORING

The physical and chemical samples were collected by MDE's Field Operations Program staff on February 10, March 16, March 23, July 22, August 19, and September 16, 1998. The physical parameters like dissolved oxygen, salinity, conductivity, and water temperature were measured *in situ* at each water quality monitoring station. Grab samples were collected for chemical and nutrient 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 Department of Health & Mental Hygiene in Baltimore, MD for chemical analysis. The field and laboratory protocols used to collect and process the samples are also described in Table A1. The February and March data were used to calibrate high flow water quality model whereas July, August, and September data were used to calibrate the low-flow water quality model for the Manokin River.

INPUT REQUIREMENTS [1]

Model Segmentation and Geometry

The spatial domain of the Manokin River Eutrophication Model (MREM) extends from just above the confluence of the Manokin River and Broad Creek for about 21.5 kilometers along the mainstem of the Manokin River. The spatial domain also includes 10.1 kilometers of Back Creek and 8.1 kilometers of Kings Creek. Following a review of the bathymetry for the Manokin River, the model was divided into 49 segments. Figure A2 shows the model segmentation and the location of the point sources. Table A2 lists the volumes, interfacial areas, and characteristic lengths of the 49 segments.

Dispersion Coefficients

The dispersion coefficients were calibrated using the WASP5.1 model and in-stream water quality data from 1998. The WASP5.1 model was set to simulate salinity. Salinity is a conservative constituent, which means there are no losses due to reactions in the water. The only source in the system is the salinity from the water at the tidal boundary at the mouth. For the model execution, all boundaries except the tidal boundary were set to zero. Flows were obtained from the USGS gage in the basin. Figure A3 shows the results of the calibration of the dispersion coefficients for high flow for the Manokin mainstem and Back Creek. Figure A4 shows the results for low-flow for the Manokin mainstem, Back Creek, and Kings Creek. The same set of dispersion coefficients was used for high flow and low-flow. Final values are listed in Table A3.

Freshwater Flows

To simulate the flows that enter the River and its tributaries, the basin was subdivided into 27 smaller watersheds. These sub-watersheds were delineated in a manner that is consistent with the finite segments developed for the MREM. In most cases, the sub-watersheds are equivalent to Maryland Department of Natural Resources (DNR) 12-digit basins. The sub-watersheds were altered where necessary to coincide with water quality monitoring stations. Figure A5 shows the Manokin River and its sub-watersheds. Each is numbered and shaded a different color.

The flows for the sub-watersheds were estimated using a United States Geological Survey (USGS) flow gage, 0148600 at the headwaters to the Manokin River. A ratio of flow to drainage area in the Manokin headwaters was calculated, then multiplied by the area of each of the sub-watersheds, to

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

obtain the flow. The 7-day consecutive lowest flow expected to occur every 10 years, known as the 7Q10 flow, for the Manokin gage was 0.0 cfs based on data from 1952-1968. Flow records were only used through March 1968, after which extensive ditching of upstream channels began. It is therefore not reasonable to assume the 7Q10 flow is currently 0.0 cfs. The critical low-flow estimated for use with the model was 0.16 cfs at the Manokin gage. This was the lowest 7-day average-flow recorded after 1968. The annual average-flow was calculated by USGS at 4.6 cfs.

The MREM was calibrated and verified for two sets of flow conditions. The first was high flow, which is represented by flow during the months of February and March. During high flow each sub-watershed was assumed to contribute a flow to the Manokin basin. The second condition was low-flow, which is represented by the months of July and August. During summer it was assumed that flow was only draining from those sub-watersheds which have free-flowing streams to carry the flows. In sub-watersheds one, two, and four it was assumed that the flow was 100% of the USGS flow. In sub-watersheds three and six it was assumed that the flow was 50% of the USGS flow. These assumptions were based on field visits to the basin during periods of low-flow. Table A4 shows the water quality segments that each sub-watershed drains to, the area of the sub-watersheds, and the flows used for the calibrations and verifications.

Point and Non-point Source Loadings

There are three point source nutrient loads that discharge directly or indirectly into the Manokin River. The Princess Anne WWTP (NPDES permit number MD0020656) discharges directly into the mainstem near the Town of Princess Anne. The Eastern Correctional Institute WWTP (NPDES permit number MD0066613) also discharges directly into the mainstem approximately 5.4 kilometers downstream from the Princess Anne WWTP outfall. The Westover Goose Creek Food Store, formerly known as The English's Family Restaurant, (NPDES permit number MD0053104) is a small wastewater treatment plant (WWTP) which discharges into the upper reach of Back Creek near Route 13. The point source loadings used in the calibration of the model were estimated using discharge monitoring reports (DMRs) from MDE's point source database. The DMRs state monthly average flows and concentrations. The flows and concentrations used in calibration and verification can be seen in Table A5.

The non-point source loadings used for the calibration of the model were calculated using in-stream data from February 10, March 23, July 22, and August 19, 1998. For high flow, data was not available for all the outlets of the sub-watersheds. A percent similarity analysis was performed using the land use data for each sub-watershed to determine which boundary station to use to estimate the non-point source load. The results can be seen in Table A6. Also for high flow, BOD data was not available, it was estimated using low-flow data. For low-flow, boundary data was available everywhere except for segment 38 (discharge from Back Creek) and segment 21 (discharge from Loretto Branch). The percent similarity analysis was used to fill in data for segment 38. After an analysis of the in-stream water quality data in the mainstem below the confluence with Loretto Branch it was determined that this branch was contributing a high load to the River that was not being correctly identified using the percent similarity analysis. For this watershed the non-point source load was estimated using station MNK0183 from the mainstem. The model was still not capturing the BOD load from Loretto Branch, so the boundary concentration was increased until the model results matched the in-stream data. The concentration was increased by a factor of 1.8. The non-point source loads reflect atmospheric deposition, loads coming from septic tanks, loads coming from urban development, agriculture, and forest land. Table A7 shows the non-point source concentrations used in the model calibration and verification.

For both point and non-point sources, the concentrations of the nutrients nitrogen and phosphorus are modeled in their speciated forms. The WASP5.1 model simulates nitrogen as ammonia (NH_3), nitrate and nitrite (NO23), and organic nitrogen (ON), and phosphorus as ortho-phosphate (PO_4) and organic phosphorus (OP). Ammonia, nitrate and nitrite, and ortho-phosphate represent the dissolved forms of nitrogen and phosphorus. The dissolved forms of nutrients are more readily available for biological processes such as algae growth, that can affect chlorophyll *a* levels and dissolved oxygen concentrations. The ratios of total nutrients to dissolved nutrients used in the model scenarios represent values that have been measured in the field.

Environmental Conditions

Eight environmental parameters were used for developing the model of the Manokin River. They are solar radiation (Table A8), photoperiod (Table A8), temperature (T) (Table A9), salinity (Table A9), extinction coefficient (K_e) (Table A10), sediment oxygen demand (SOD) (Table A10), sediment ammonia flux (FNH_4) (Table A10), and sediment phosphate flux (FPO_4) (Table A10). During high flow conditions during the winter there were no nutrient fluxes from the sediment, and the SOD was constant at 0.5 $g\ O_2/m^2\ day$. Data for the solar radiation and photoperiod were taken from a water quality modeling study performed on the Potomac River (HydroQual, 1982). Data for salinity and temperature were taken from in-stream water quality measurements. Initial values for SOD, FNH_3, and FPO_4 were estimated then refined through the calibration of the model.

Table A8: Solar Radiation and Photoperiod used in the Calibration and Verification of the MREM

		Feb	Mar	July	Aug
Total Daily Solar Radiation	*langleys*	232	320	475	374
Photoperiod	*fraction of a day*	0.45	0.52	0.50	0.55

Light extinction coefficients, K_e in the water column were derived from the 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)

Nonliving organic nutrient components settle from the water column into the sediment at a settling rate velocity of 0.00864 *m/day*, and phytoplankton settles from the water column at a rate of 0.293 *m/day*. In general, 50% of the nonliving organics were considered in the particulate form. Further, 15% of the orthophosphate was considered in the particulate form. Such assignments were borne out through model sensitivity analyses.

The SOD in the middle to upper reaches of the river was taken to be higher due to the high concentrations of chlorophyll *a* which were settling out and the high inputs of nutrients. A maximum value of 3.0 $g\ O_2/m^2 day$ was used. This value is considered reasonable based on the condition of the stream and the values in the literature (Thomann and Mueller, 1987).

Kinetic Coefficients

The water column kinetic coefficients are universal constants used in the MREM model. They are formulated to characterize the kinetic interactions among the water quality constituents. The initial values were taken from past modeling studies of Potomac River (Clark and Roesh, 1978; Thomann and Fitzpatrick, 1982; Cerco, 1985), and of Mattawoman Creek (Haire and Panday, 1985, Panday and Haire, 1986, Domotor *et al*., 1987), and the Patuxent River (Lung, 1993). The kinetic coefficients are listed in Table A11.

Initial Conditions

The initial conditions used in the model were as close to the observed values as possible. However, since the model was run for a long period of time (100 days) it was found that initial conditions did not impact the final results.

CALIBRATION & SENSITIVITY ANALYSIS

The MREM model for high flow was calibrated with March 1998 data, then validated using February 1998 data. The MREM for low-flow was calibrated with July 1998 data, then validated using August 1998 data. Table A5 shows the point source loads and flows associated with the calibration input files, and Table A7 shows the non-point source flows and concentrations. Figures A6 – A8 show the results of the high flow calibration runs for the mainstem, Back Creek, and Kings Creek and the March 23, 1998 water quality data. Figures A9 – A11 show the results of the high flow verification runs, and the February 22, 1998 water quality data. Figures A12 –A14 show the results of the low-flow calibration runs for the mainstem, Back Creek and

Kings Creek, and the July 22, 1998 water quality data. Finally, Figures A15-A17 show the results of the verification of the low-flow model, and the August 19, 1998 water quality data.

SYSTEM RESPONSE

The EUTRO5.1 model of Manokin River was applied to several different point and non-point source loading conditions under various stream flow conditions to project the impacts of nutrients and BOD on eutrophication and low dissolved oxygen in the River. By modeling various stream flows, the model runs simulate seasonality.

Model Run Descriptions

The first scenario represents the critical conditions of the stream during low-flow. The flow at the USGS gage in the Manokin was the lowest 7-day average-flow recorded after 1968 (0.16 cfs). The total non-point source (NPS) loads were computed using 1998 base-flow field data. The non-point source loads reflect atmospheric deposition, loads from septic tanks, and other non-point source loads coming off the land. The point source loads reflect maximum design flows and estimated future maximum concentrations at all WWTPs. Most of the environmental parameters and kinetic coefficients used for the calibration of the model remained the same for scenario 1. The temperature was changed to a long-term summer average (July, August, and September) of 26.2 ^{o}C for all segments, based on DNR water quality monitoring station MET8.1 for the years 1986-1999.

The second scenario represents the critical conditions of the stream during average-flow. The flow at the USGS gage in the Manokin was the annual average-flow (4.6 cfs), according to USGS. The non-point source loads were determined using land use loading coefficients. The land use information was based on 1997 Maryland Office of Planning data, adjusted using 1997 Farm Service Agency (FSA) data. The total non-point source load was calculated by summing all of the individual land use areas and multiplying by the corresponding land use loading coefficients. The loading coefficients were based on the results of the Chesapeake Bay Model (U.S. EPA, 1996), which was a continuous simulation model. They account for both atmospheric deposition and loads from septic tanks. The loading rates predicted loads for the year 2000 assuming Best Management Practice (BMP) implementation at a level consistent with current progress. The non-point source concentrations of nitrogen, phosphorus, and CBOD for model scenarios 1 and 2 can be seen in Table A11 and Table A12. The point source loads reflect maximum design flows and estimated future maximum concentrations at all WWTPs.

The loading rates used in the average-flow scenario only predict nutrient loads. The model still requires boundary conditions for chlorophyll *a*, CBOD, and dissolved oxygen. The concentrations of chlorophyll *a* and CBOD tend to be higher in summer and the concentrations of dissolved oxygen tend to be lower during the summer. These are the more critical conditions. Thus for the average-flow scenario, the missing boundary concentrations for these constituents was filled in using an average of July, August, and September 1998 data from both MDE and DNR stations. The dissolved oxygen boundaries for segment 38 (Back Creek) and segment 49 (Kings Creek) were increased to 5.0 mg/l, because during average-flow conditions, it is expected that there will be increased reaeration due to increased turbulence from the increase flow, in

comparison to low-flow conditions. All the kinetic coefficients and environmental parameters remained the same as for scenario 1.

In the next two scenarios, the model was used to predict the water quality response in the River with different sets of load reductions. There are three WWTPs in the Manokin Basin. Eastern Correctional Institute WWTP and Princess Anne WWTP have monthly NPDES permit limits for nutrients that are very restrictive. The Westover Goose Creek Food Store has a very small discharge (0.006 mgd). Therefore, when nutrient reductions were being considered, the point source loads were not reduced from the base-line scenario.

Model sensitivity analysis were performed on the critical condition scenarios for low flow and average flow to determine the reaction of the model to reductions in both nitrogen and phosphorus. The model was sensitive to reductions in nitrogen. However, it was not very sensitive to reductions in phosphorus. During low flow conditions a 100% increase in point source and non-point source total phosphorus loads had no effect on chlorophyll *a* or dissolved oxygen concentrations. During average flow the model did show a slight sensitivity to increased phosphorus. However it was very slight and did not affect the chlorophyll *a* or dissolved oxygen significantly. Thus when determining non-point source load reductions, only nitrogen and BOD were reduced.

The third scenario represents improved conditions in the stream during low-flow. The flow at the USGS gage in the Manokin was the same as scenario one. The total non-point source loads were an average of July, August, and September 1998 base-flow field data collected by MDE and DNR. The nitrogen loads were reduced to meet chlorophyll *a* standards in the water. The BOD loads were reduced to meet dissolved oxygen standards in the water. The final low-flow non-point source nutrient concentrations used in the model and the percent load reductions can be seen in Table A13. The point source loads reflect maximum design flows and estimated future maximum concentrations at all WWTPs. More information about point and non-point source loads can be found in the Technical Memorandum entitled "Significant Nitrogen and Biochemical Oxygen Demand Point and Non-point Sources in the Manokin River Watershed."

When estimating feasible nitrogen non-point source reductions, it was only reasonable to assume reductions for controllable loads. The percent of the load that was controllable was estimated for each sub-watershed. It was assumed that all of the loads from cropland, feedlots, and urban were controllable, and that loads from pasture, atmospheric deposition, septic tanks, and forest were not controllable. This analysis was performed on the average annual loads, because loads from specific land uses were not available for low-flow. However, the percent controllable was applied to the low-flow loads as well as the average annual loads. Several model loading scenarios were performed for both low-flow and average-flow to estimate the necessary reductions in controllable load, to meet the chlorophyll *a* goal.

The reduction in nitrogen also affects the starting concentrations of chlorophyll *a* in the river. The amount of nitrogen available for algae growth was calculated after the reduction in loads, to help estimate the amount of chlorophyll *a* at the boundaries. A nitrogen to chlorophyll *a* ratio of 7.5 was assumed. If the calculated value was higher than the original value, the original value was used.

For scenario 3, all of the kinetic coefficients remained the same as for the calibration of the model. Most of the environmental parameters remained the same. However, it was expected that the ammonia fluxes from the sediment as well as the sediment oxygen demand would change with reductions in nutrients and BOD.

The following method was developed to estimate the changes in nitrogen fluxes from the sediment layer. First an initial estimate was made of the total organic nitrogen settling to the sediments, from particulates, living algae, and phaeophytin, in each segment, for the low-flow calibration. This was done by running the calibration of the model once with correct settling of organic nitrogen and chlorophyll *a*, then again with no settling. The difference between the two runs was assumed to settle to the sediments. All phaeophytin was assumed to settle to the bottom. The amount of phaeophytin was estimated from in-stream water quality data. To calculate the organic loads from the algae, a nitrogen to chlorophyll *a* ratio of 7.5 was used. This analysis was then repeated for scenario 3. The percentage difference between the amount of nitrogen that settled in the calibration of the model and the amount that settled in scenario 3 was then applied to the ammonia fluxes in each segment. Scenario 3 was then run again with the updated fluxes. A new amount of settled organics was calculated, and new fluxes were calculated. The process was repeated several times, until the fluxes remained constant.

Along with changes in nitrogen fluxes from the sediments, when the nitrogen and BOD loads to the system are reduced, the sediment oxygen demand will also be reduced. It was assumed that the SOD would be reduced in the same proportion as the nitrogen fluxes, to a minimum of $0.5\ g\ O_2/m^2\ day$.

After the reductions in nitrogen, chlorophyll *a*, ammonia fluxes, and SOD were incorporated into the boundary conditions, the BOD load to the river was reduced where necessary to meet the water quality standard of 5 mg/l of dissolved oxygen in the river. The reduction to BOD was from the total load because data was not available to determine the controllable portion of the load.

The fourth scenario represents improved conditions in the stream during average-flow. The flow at the USGS gage in the Manokin was the same as scenario 2. The total non-point source loads were similar to scenario 2. The nitrogen loads were reduced to meet chlorophyll *a* standards in the water. The final average-flow non-point source nutrient concentrations used in the model and the percent load reductions can be seen in Table A14. All of the kinetic coefficients remained the same as for scenario 2. Most of the environmental parameters remained the same. The ammonia and the SOD that were used in the model were the same as for scenario 3. The point source loads reflect maximum design flows and estimated future maximum concentrations at all WWTPs. More information about point and non-point source loads can be found in the Technical Memorandum entitled "Significant Nitrogen and Biochemical Oxygen Demand Point and Non-point Sources in the Manokin River Watershed."

Scenario Results

Critical Condition Scenarios:

1. *Low-flow:* Assumes low stream flow conditions. Assumes the 1998 base-flow non-point source loads, and maximum design flows and loads at all the WWTPs.

2. *Average Annual Flow:* Assumes average stream flow conditions. Assumes the 2000 average annual non-point source loads, and maximum design flows and loads at all the WWTPs.

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

The first scenario represents the critical summer low-flow conditions when water quality is impaired by high chlorophyll *a* levels, and low dissolved oxygen concentrations. The second scenario represents critical conditions during average-flow. The results for scenarios 1 and 2 for the main branch, Back Creek, and Kings Creek can be seen in Figures A18-A20. In both scenarios, the peak chlorophyll *a* levels are above the desired goal of 50 µg/l. It can be seen that the dissolved oxygen level falls below the standard of 5 mg/l in scenario 1.

Future Condition Scenarios:

3. *Low-flow:* Assumes low stream flow conditions. Assumes a total nitrogen load reduction of 18% (24% of controllable), a total phosphorus load reduction of 0%, and a total BOD load reduction of 26% based on the 1998 base-flow non-point source loads, plus a 5% margin of safety. Assumes point source loads for the summer low-flow critical conditions make up the balance of the total allowable load.

4. *Average Annual Flow:* Assumes average stream flow conditions. Assumes a total nitrogen load reduction of 21% (33% of controllable) and a total phosphorus load reduction of 27% (33% of controllable) based on the 2000 average annual non-point source loads, plus a 5% margin of safety. Assumes point source loads for the average annual conditions make up the balance of the total allowable load.

The results of the third scenario indicate that, under summer low-flow conditions, the water quality target for dissolved oxygen and chlorophyll *a* is satisfied at all locations within the modeling domain. The results from scenario 4 also indicate that under average-flow conditions, the water quality target for dissolved oxygen and chlorophyll *a* is satisfied at all locations within the modeling domain. The results for scenarios 3 and 4 can be seen in Figures A21-A23.

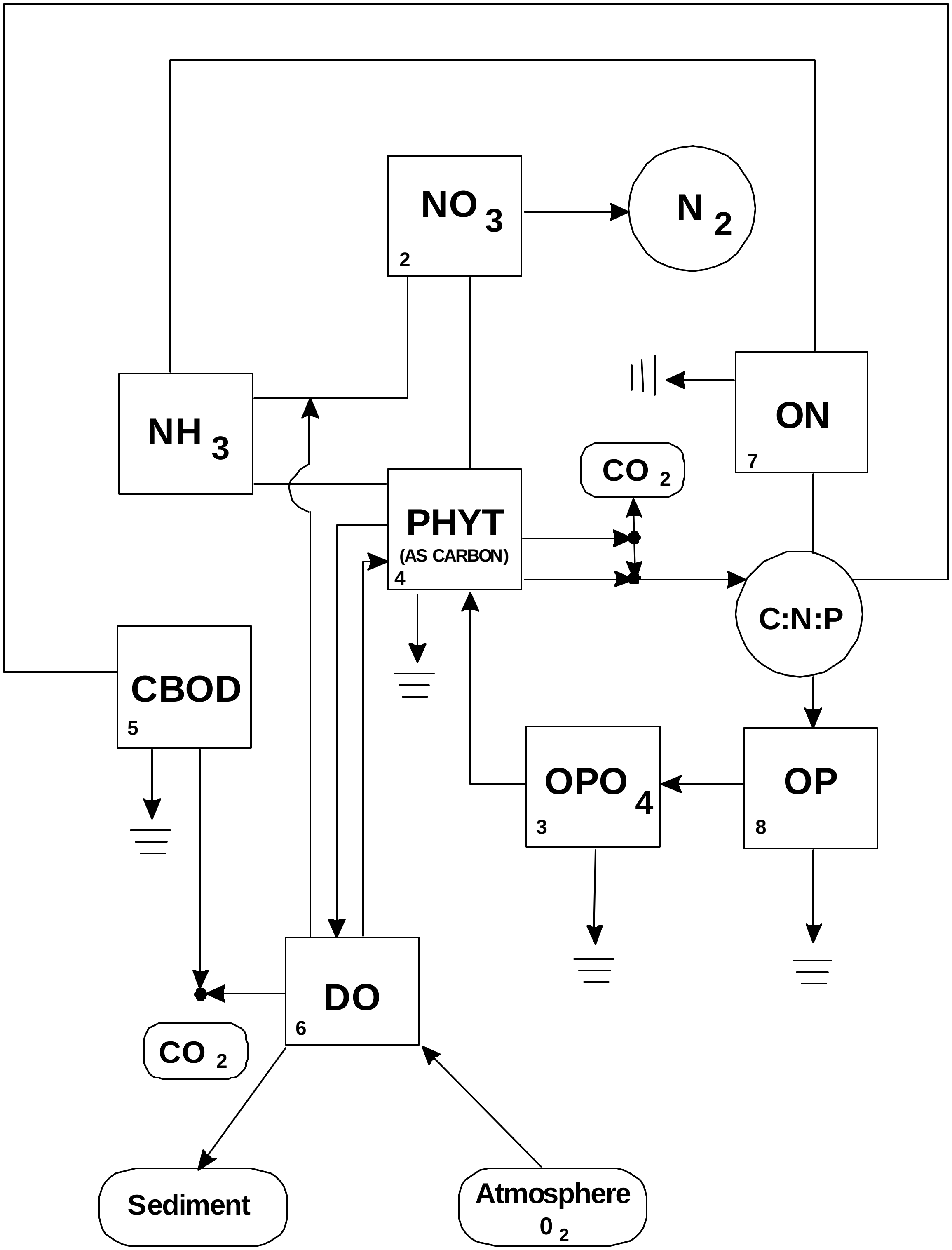


Figure A1: State Variables and Kinetic Interactions in EUTRO5

Table A1: Field and Laboratory Protocols

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

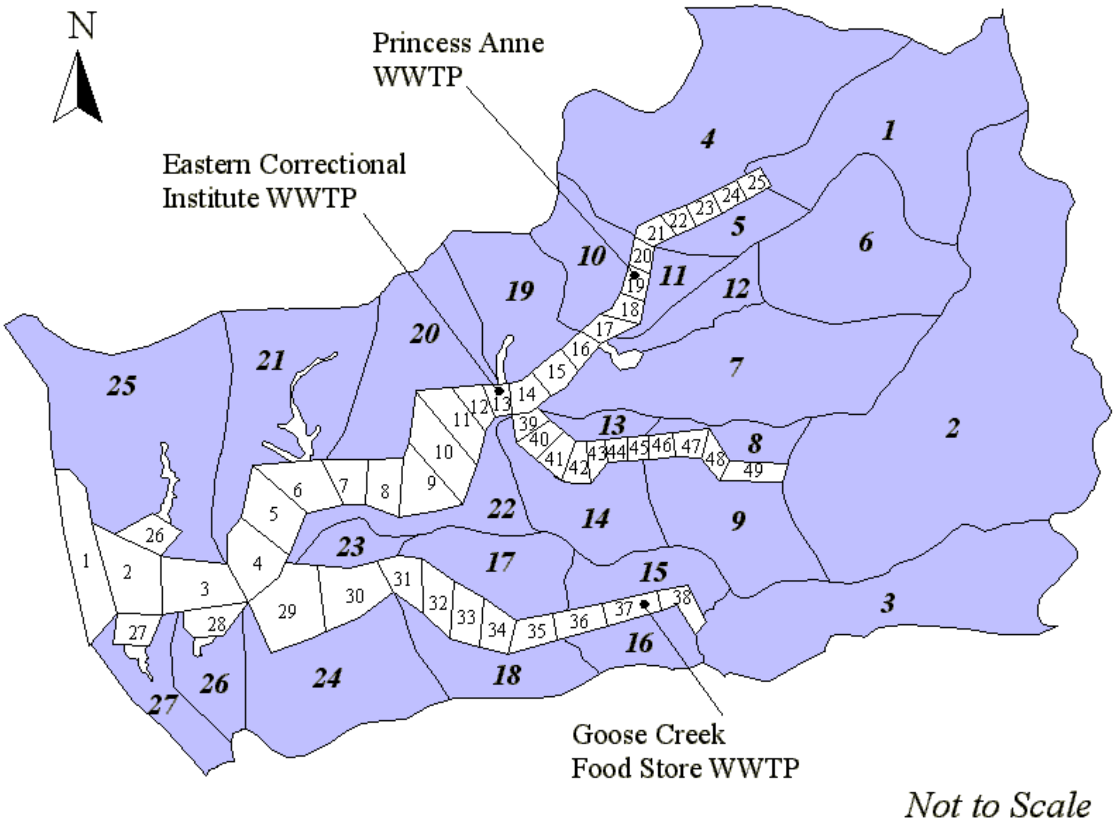


Figure A2: Manokin River Model Segmentation and Location of Point Sources

Table A2: Volumes, Interfacial Areas, and Characteristic Lengths for the MREM

Segment Pair	Volume (m3)	Interfacial Area (m2)	Characteristic Length (m)
1	2,607,393	3,644.1	920
2	2,449,592	2,024.1	1,085
3	1,500,660	1,895.2	1,255
4	699,734	850.1	1,280
5	247,576	226.5	1,107
6	210,957	315.3	914
7	119,409	146.3	914
8	119,409	115.0	914
9	131,298	120.2	960
10	97,734	188.1	983
11	93,904	115.0	983
12	123,522	71.9	914
13	79,001	53.0	821
14	117,986	139.7	863
15	82,736	121.0	953
16	69,097	68.1	952
17	40,291	56.2	852
18	34,403	41.1	750
19	31,415	37.8	700
20	28,427	34.4	700
21	25,076	31.0	700
22	21,691	27.7	690
23	18,674	24.4	675
24	15,762	21.1	667
25	13,022	18.0	658
26	81,160	108.7	1,029
27	385,733	926.7	1,029
28	328,877	853.5	723
29	535,249	582.6	1,173
30	116,039	131.1	1,450
31	35,981	34.7	1,350
32	19,020	20.7	1,250
33	12,111	11.0	1,200
34	10,596	10.1	1,150
35	9,651	9.2	1,100
36	8,310	8.3	1,100
37	6,739	7.5	1,050
38	5,716	6.7	950
39	73,004	60.8	490
40	58,852	79.2	930
41	40,652	47.4	915
42	36,053	43.0	900
43	31,651	38.5	885
44	27,603	34.2	870
45	23,683	30.0	860
46	19,889	25.8	850
47	16,121	21.6	840
48	12,677	17.5	825
49	9,363	13.5	819

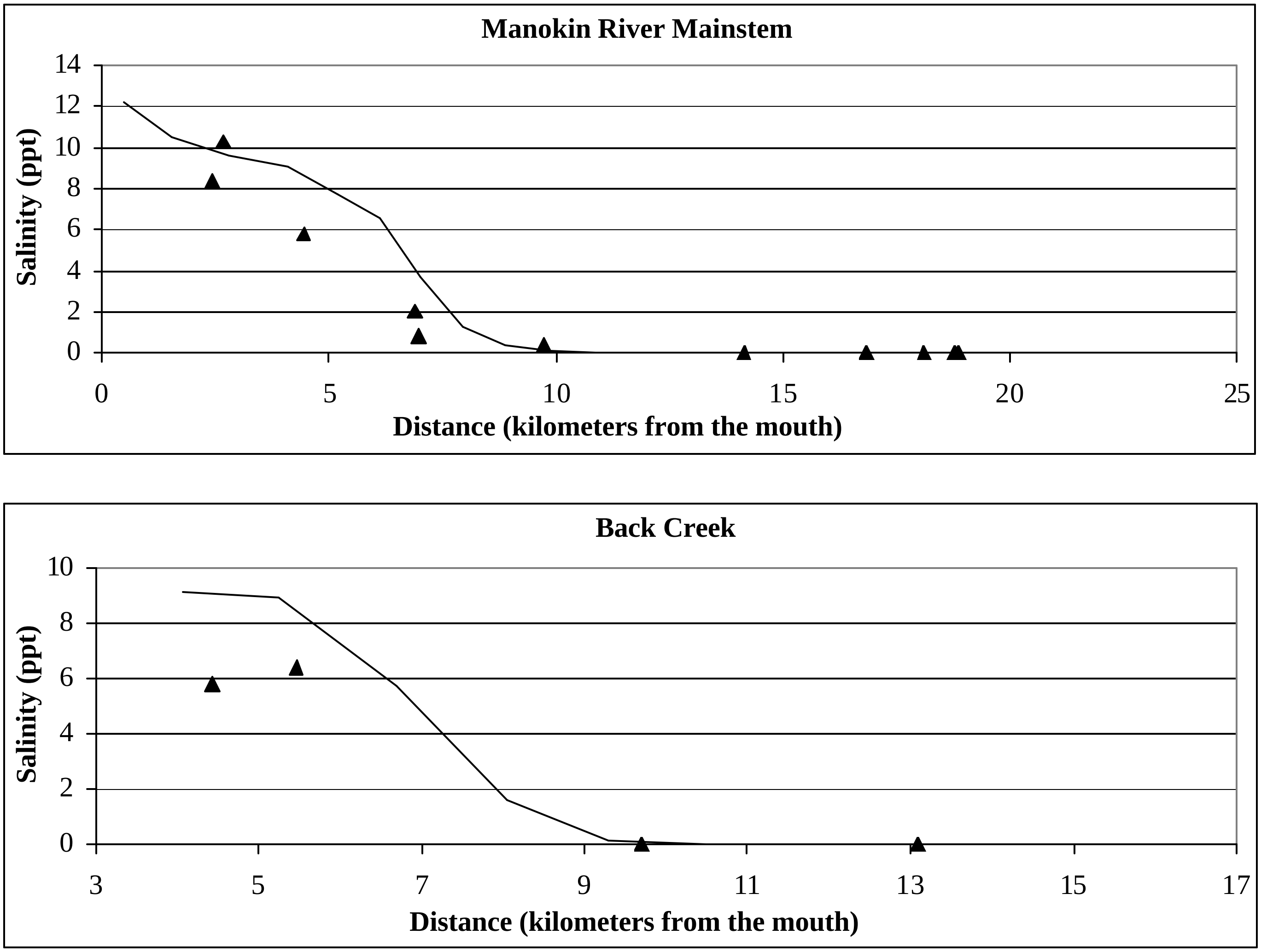


Figure A3: Results of the Calibration of Exchange Coefficients for High-flow

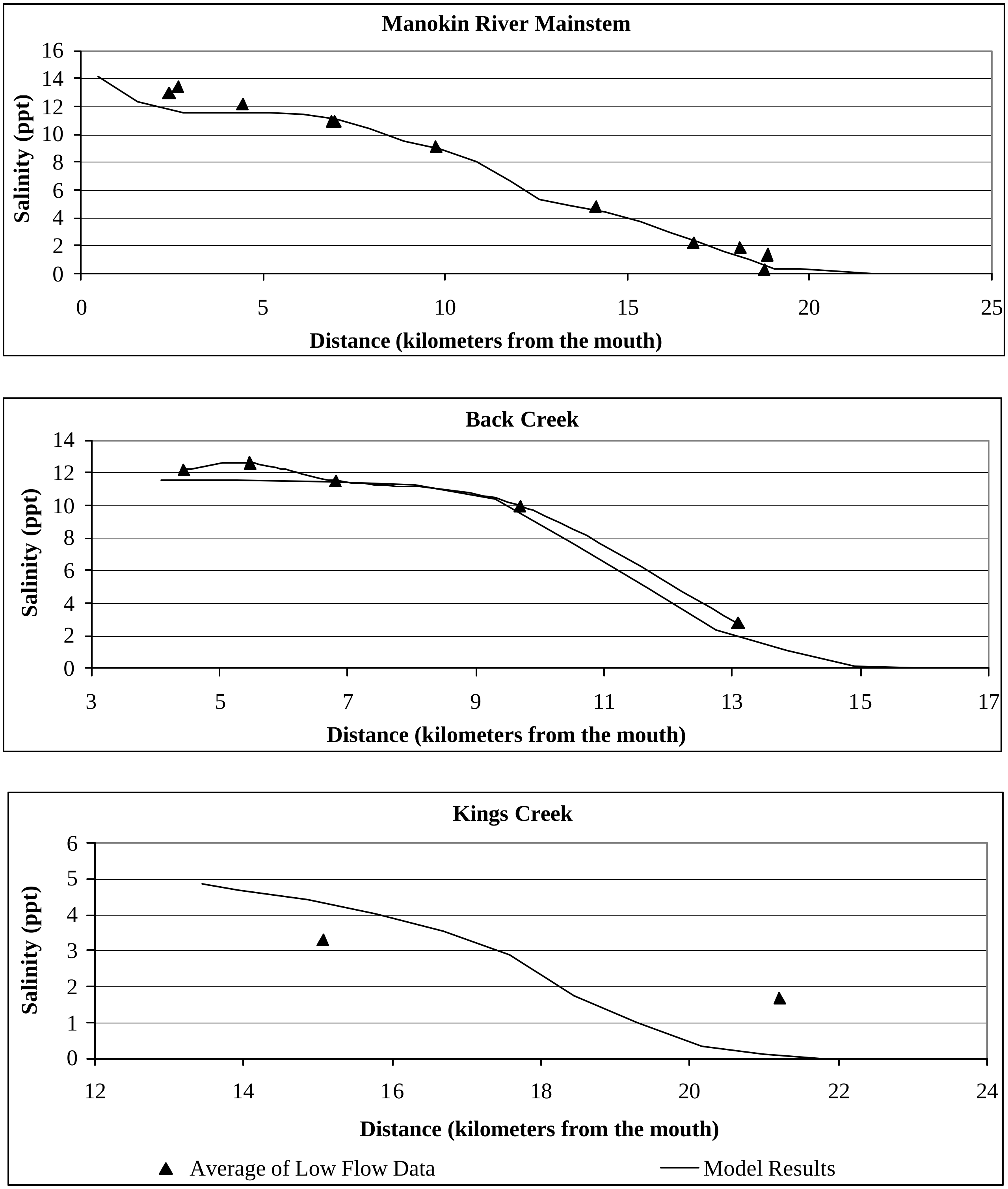


Figure A4: Results of the Calibration of Exchange Coefficients for Low-flow

Table A3: Dispersion Coefficients used in the MREM

Exchange Pair	Dispersion Coefficient (m^2/sec)	Exchange Pair	Dispersion Coefficient (m^2/sec)
0-1	200	2-26	90
1-2	190	26-0	90
2-3	190	2-27	90
3-4	180	27-0	90
4-5	160	2-28	90
5-6	95	28-0	90
6-7	45	4-29	90
7-8	25	29-30	20
8-9	20	30-31	15
9-10	17	31-32	7
10-11	16	32-33	3
11-12	15	33-34	2
12-13	14	34-35	1
13-14	13	35-36	1
14-15	12	36-37	0.2
15-16	12	37-38	0.2
16-17	10	38-0	0.01
17-0	3	14-39	10
17-18	8	39-40	10
18-19	6	40-41	10
19-20	4	41-42	8
20-21	3	42-43	5
21-0	3	43-44	2
21-22	1	44-45	2
22-23	1	45-46	0.9
23-24	0.5	46-47	0.9
24-25	0.5	47-48	0.1
25-0	0	48-49	0.1
		49-0	0.1

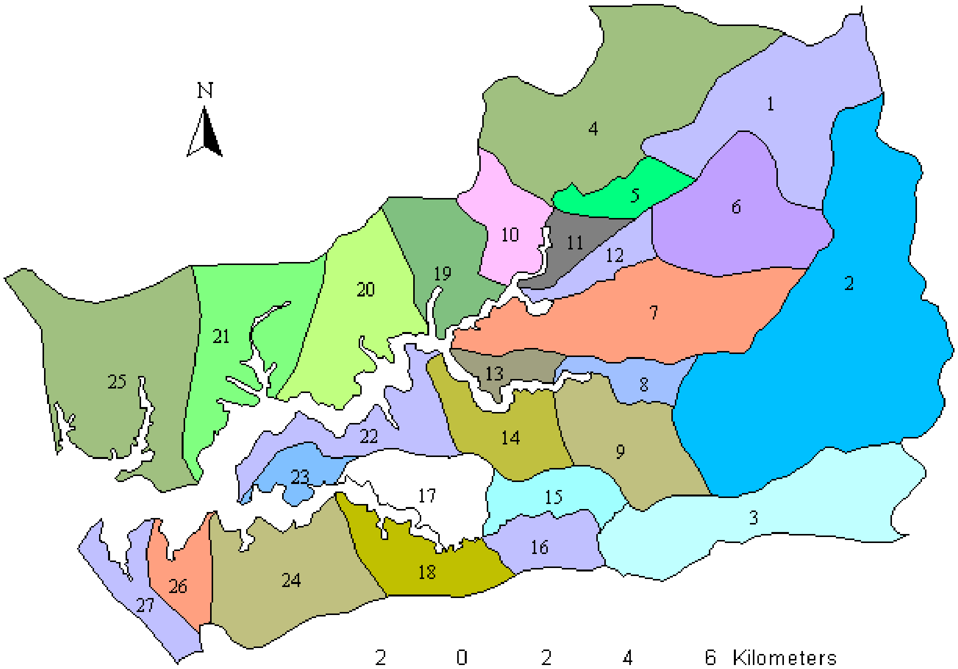


Figure A5: Manokin River Sub-watersheds

Table A4: Contributing Sub-watershed to each Water Quality Segment, Sub-watershed area, and Flows used in the Calibration and Verification

Flows to Segment	Sub-watershed	Area km^2	Feb. 10 Flow (m^3/s)	March 23 Flow (m^3/s)	July Average Flow (m^3/s)	Aug. Average Flow (m^3/s)
6	21	5.79	0.247	0.453	0.0000	0.0000
9	22	5.57	0.238	0.436	0.0000	0.0000
10	20	8.70	0.372	0.681	0.0000	0.0000
14	19	9.81	0.419	0.769	0.0000	0.0000
17	6 +12+7	25.24	1.078	1.977	0.0143	0.0053
18	11	2.14	0.091	0.167	0.0000	0.0000
20	10	4.06	0.173	0.318	0.0000	0.0000
21	4	17.55	0.750	1.375	0.0346	0.0129
23	5	2.70	0.115	0.212	0.0000	0.0000
25	1	12.30	0.526	0.964	0.0364	0.0136
26	25	15.30	0.654	1.199	0.0000	0.0000
27	27	3.12	0.133	0.244	0.0000	0.0000
28	26	3.12	0.133	0.244	0.0000	0.0000
29	23	2.05	0.088	0.161	0.0000	0.0000
30	24	9.69	0.414	0.759	0.0000	0.0000
31	17	5.30	0.226	0.415	0.0000	0.0000
34	18	5.16	0.221	0.404	0.0000	0.0000
36	15+16	6.96	0.297	0.545	0.0000	0.0000
38	3	12.76	0.545	1.000	0.0189	0.0070
40	13	1.84	0.079	0.144	0.0000	0.0000
42	14	5.19	0.222	0.407	0.0000	0.0000
47	8	2.34	0.100	0.183	0.0000	0.0000
48	9	7.07	0.302	0.554	0.0000	0.0000
49	2	32.53	1.390	2.548	0.0961	0.0359
Total		**206.29**	**8.814**	**16.159**	**0.2002**	**0.0748**

Table A5: Point Source Flows and Concentrations used in the Calibration and Verification of the MREM

		Eastern Correctional Institute WWTP MD0066613			
		February	*March*	*July*	*August*
NH4	*kg/d*	0.2410	0.307	0.2715	0.6464
NO23	*kg/d*	3.0199	1.8730	0.48	1.37
PO4	*kg/d*	0.1276	0.1171	0.078	0.065
CBODu	*kg/d*	2.3630	2.4388	2.15	2.15
DO	*kg/d*	11.626	10.682	8.79	8.53
TON	*kg/d*	0.9925	0.7463	0.543	0.310
OP	*kg/d*	0.02836	0.02927	0.01	0.01
FLOW	*m3/s*	0.016381	0.016907	0.0149	0.0165

		Princess Anne WWTP MD0020656			
		February	*March*	*July*	*August*
NH4	*kg/d*	4.2945	0.204	0.1327	0.1327
NO23	*kg/d*	23.6020	14.8869	20.85	20.66
PO4	*kg/d*	0.3142	0.2043	0.209	0.227
CBODu	*kg/d*	22.6943	17.0275	8.85	9.16
DO	*kg/d*	22.345	16.055	11.56	11.37
TON	*kg/d*	7.4367	4.6704	1.460	1.516
OP	*kg/d*	0.27931	0.14595	0.06	0.11
FLOW	*m3/s*	0.040340	0.033726	0.0219	0.0188

		Westover Goose Creek Store MD0053104			
		February	*March*	*July*	*August*
NH4	*kg/d*	0.2253	0.220	0.3329	0.3329
NO23	*kg/d*	0.0255	0.0249	0.04	0.04
PO4	*kg/d*	0.0420	0.0411	0.062	0.062
CBODu	*kg/d*	0.0278	0.0272	0.04	0.08
DO	*kg/d*	0.178	0.119	0.19	0.19
TON	*kg/d*	0.0494	0.0483	0.073	0.073
OP	*kg/d*	0.00801	0.00782	0.01	0.01
FLOW	*m3/s*	0.000193	0.000188	0.0003	0.0003

Table A6: Results of the Percent Similarity Analysis

Water Quality Segment	MREM Subwatershed	Most Simliar to Subwatershed	Representative Water Quality Station
6	21	2	KNG0064
9	22	2	KNG0064
10	20	3/1	BXK0095
14	19	2	KNG0064
17	7	2	KNG0064
17	6+7+12	6	TLY0000
18	11	2	KNG0064
20	10	2	KNG0064
21	4		MNK0183
23	5	6	MNK0015
25	1	1	MKB0015
26	25	1	MKB0015
27	27	1	MKB0015
28	26	1	MKB0015
29	23	1	MKB0015
30	24	1	MKB0015
31	17	2	KNG0064
34	18	2	KNG0064
36	15	2	KNG0064
36	16	2	KNG0064
38	3	3/2	BXK0095
40	13	2	KNG0064
42	14	2	KNG0064
47	8	2	KNG0064
48	9	2	KNG0064
49	2	2	KNG0064

Note: A slash and a second number means this was the second most similar sub-watershed

Table A7: Non-point Source Concentrations used in the Calibration and Verification of the MREM

February 10, 1998 Data

Station Name	NH4 *mg/l*	NO23 *mg/l*	PO4 *mg/l*	CHAA *ug/l*	CBODu *mg/l*	DO_fld *mg/l*	ON *mg/l*	OP *mg/l*
TYL0000	0.091	1.28	0.0585	2.24	3.33	11.6	0.892	0.0857
XBI8199	0.029	0.22	0.0232	5.38	3.33	10.7	0.676	0.0435
MNK0183	0.155	1.54	0.0270	0.75	3.33	8.60	0.642	0.0445
MKB0015	0.126	1.90	0.0190	1.12	3.33	9.40	0.524	0.0230
BXK0095	0.052	0.11	0.0987	1.12	3.33	8.20	0.768	0.0316
KNG0064	0.047	0.44	0.0306	1.12	3.33	9.10	0.695	0.0197

March 23, 1998 Data

Station Name	NH4 *mg/l*	NO23 *mg/l*	PO4 *mg/l*	CHAA *ug/l*	CBODu *mg/l*	DO *mg/l*	ON *mg/l*	OP *mg/l*
XBI8199	0.016	0.20	0.0233	23.92	3.33	11.1	0.735	0.0185
TYL0000	0.135	0.62	0.1684	1.50	3.33	8.7	0.945	0.1233
MNK0183	0.112	0.88	0.0562	0.75	3.33	8.80	0.792	0.0341
MKB0015	0.122	1.33	0.0322	2.14	3.33	9.30	0.628	0.0364
BXK0095	0.196	0.14	0.1552	0.75	3.33	8.00	0.819	0.0635
KNG0064	0.072	0.34	0.0572	3.29	3.33	8.50	0.761	0.0265

July 22, 1998 Data

Station Name	NH4 *mg/l*	NO23 *mg/l*	PO4 *mg/l*	CHAA *ug/l*	CBODu *mg/l*	DO *mg/l*	ON *mg/l*	OP *mg/l*
XBI8199	0.000	0.00	0.0187	15.25	6.83	5.3	0.770	0.0286
TYL0000	0.003	0.00	0.0650	82.24	9.83	6.3	1.803	0.1351
MNK0183	0.017	0.01	0.1204	368.82	32.00	13.10	4.076	0.2640
MKB0015	0.056	0.52	0.0230	3.36	4.83	6.60	0.104	0.0404
BXK0095	0.137	0.97	0.1062	2.49	5.50	4.50	1.073	0.2013
KNG0064	0.137	0.97	0.1062	2.49	5.50	4.50	1.073	0.2013

August 19, 1998 Data

Station Name	NH4 *mg/l*	NO23 *mg/l*	PO4 *mg/l*	CHAA *ug/l*	CBODu *mg/l*	DO *mg/l*	ON *mg/l*	OP *mg/l*
XBI8199	0.006	0.00	0.0237	11.71	2.50	6.6	0.816	0.0392
TYL0000	0.010	0.00	0.0867	56.07	3.00	5.1	2.063	0.1651
MNK0183	0.014	0.52	0.2556	302.78	33.00	8.10	3.988	0.2104
MKB0015	0.051	0.03	0.0476	4.49	2.83	3.70	1.418	0.0706
BXK0095	0.204	1.16	0.1629	1.50	3.00	5.50	0.444	0.0896
KNG0064	0.204	1.16	0.1629	1.50	3.00	5.50	0.444	0.0896

Table A9: Temperatures and Salinity used in the Calibration and Verification of the MREM

Segment	T Feb °C	T Mar °C	T July °C	T Aug °C	Salinity Feb g/L	Salinity Mar g/L	Salinity July g/L	Salinity Aug g/L
1	5.5	7.0	29.5	26.5	11.6	11.6	10.6	13.5
2	5.5	7.0	29.5	26.5	10.9	10.9	10.5	13.3
3	5.0	7.0	29.5	26.5	10.5	10.5	10.5	13.2
4	5.0	7.0	30.0	26.5	8.1	8.1	8.6	12.2
5	5.0	7.0	30.0	26.5	6.9	6.9	8.3	11.8
6	5.5	7.5	30.0	26.5	5.4	5.4	7.9	11.3
7	5.5	7.5	30.0	26.5	4.1	4.1	7.6	10.9
8	5.5	7.5	30.0	26.5	3.2	3.2	7.0	10.2
9	5.5	7.5	29.5	26.5	2.3	2.3	6.4	9.7
10	5.5	7.5	29.5	26.5	1.6	1.6	5.8	9.2
11	5.5	7.5	29.5	26.5	0.8	0.8	4.8	8.1
12	5.5	7.5	29.5	27.0	0.6	0.6	4.0	7.1
13	5.5	7.5	30.0	27.0	0.3	0.3	3.2	6.3
14	5.5	8.0	30.0	27.5	0.0	0.0	2.4	5.5
15	5.5	8.0	30.0	27.5	0.0	0.0	1.8	4.8
16	5.5	8.0	33.0	27.5	0.0	0.0	1.0	3.6
17	5.5	8.0	33.0	27.0	0.0	0.0	0.4	2.8
18	5.5	8.0	29.5	27.0	0.0	0.0	0.7	2.7
19	5.5	8.0	29.5	27.0	0.0	0.0	0.4	2.2
20	5.0	8.0	29.5	26.5	0.0	0.0	0.2	1.9
21	7.3	8.5	30.0	26.5	0.0	0.0	0.6	0.9
22	7.3	8.5	30.0	22.0	0.0	0.0	0.5	0.6
23	7.6	8.0	30.0	22.0	0.0	0.0	0.4	0.5
24	7.6	8.0	30.0	22.0	0.0	0.0	0.2	0.3
25	7.6	8.0	30.0	22.0	0.0	0.0	0.0	0.0
26	5.0	7.0	30.0	26.5	8.1	8.1	8.6	12.2
27	5.0	7.0	30.0	26.5	8.1	8.1	8.6	12.2
28	5.0	7.0	30.0	26.5	8.1	8.1	8.6	12.2
29	5.0	7.0	29.5	26.5	6.1	6.1	8.6	12.6
30	5.5	7.5	29.5	26.5	4.3	4.3	10.2	11.5
31	5.5	8.0	30.0	26.5	2.4	2.4	8.8	10.8
32	5.5	8.5	30.0	26.5	0.0	0.0	7.3	9.9
33	5.5	8.5	29.5	26.5	0.0	0.0	5.6	8.2
34	5.5	8.5	29.5	26.5	0.0	0.0	4.4	5.8
35	5.0	8.5	28.5	26.5	0.0	0.0	2.8	3.5
36	5.0	8.5	28.5	26.5	0.0	0.0	0.9	2.8
37	5.0	8.5	28.5	26.5	0.0	0.0	0.3	1.0
38	5.0	8.5	28.5	26.5	0.0	0.0	0.0	0.0
39	5.5	8.0	30.0	27.0	0.0	0.0	2.2	4.8
40	5.5	8.5	30.0	26.5	0.0	0.0	1.8	3.3
41	5.5	8.5	30.0	26.5	0.0	0.0	1.6	3.1
42	5.5	8.5	30.0	26.5	0.0	0.0	1.4	2.9
43	5.5	8.5	30.0	26.5	0.0	0.0	1.2	2.6
44	5.5	8.5	30.0	26.5	0.0	0.0	1.0	2.4
45	5.5	8.5	28.5	27.0	0.0	0.0	0.8	2.2
46	5.5	8.5	28.5	27.0	0.0	0.0	0.6	1.9
47	5.5	8.5	28.5	27.0	0.0	0.0	0.4	1.7
48	5.5	8.0	28.5	26.5	0.0	0.0	0.3	1.4
49	5.5	7.5	28.5	22.0	0.0	0.0	0.0	0.0

Table A10: Extinction Coefficients, Sediment Oxygen Demand, and Nutrient Fluxes used in the Calibration and Verification of the MREM

Segment	K_e		SOD	FNH_4	FPO_4
	High Flow	Low Flow	Low Flow	Low Flow	Low Flow
	m^{-1}	m^{-1}	$g\ O_2/m^2\ day$	$mg\ NH_4\_N/m^2\ day$	$mg\ PO_4\_P/m^2\ day$
1	5.5	2.5	0.5	1.0	0.1
2	5.5	2.5	0.5	1.0	0.1
3	5.5	2.5	0.5	1.0	0.1
4	10.0	6.5	0.5	1.0	0.1
5	10.0	6.5	0.5	1.0	0.1
6	10.0	6.5	0.5	1.0	0.1
7	10.0	6.5	0.5	1.0	0.1
8	12.0	5.5	0.5	1.0	0.1
9	15.0	5.5	1.0	1.0	0.1
10	19.5	4.8	2.0	1.0	0.1
11	19.5	4.8	2.0	1.0	0.1
12	19.5	4.8	2.5	1.0	0.1
13	19.5	4.8	3.0	1.0	0.1
14	19.5	4.8	3.0	1.0	0.1
15	19.5	4.8	3.0	5.0	0.5
16	15.0	4.8	3.0	10.0	1.0
17	12.0	4.8	3.0	10.0	1.0
18	12.0	4.8	2.5	20.0	2.0
19	10.0	4.8	2.5	20.0	2.0
20	10.0	4.8	2.5	20.0	2.0
21	10.0	4.8	1.5	15.0	1.5
22	10.0	5.5	1.0	15.0	1.5
23	10.0	5.5	0.5	10.0	1.0
24	10.0	5.5	0.5	5.0	0.5
25	10.0	5.5	0.5	1.0	0.1
26	10.0	4.8	0.5	1.0	0.1
27	10.0	4.8	0.5	1.0	0.1
28	10.0	4.8	0.5	1.0	0.1
29	5.5	4.8	0.5	1.0	0.1
30	5.5	4.8	0.8	1.0	0.1
31	10.0	4.8	1.0	1.0	0.1
32	10.0	4.8	0.8	1.0	0.1
33	10.0	4.8	0.8	2.0	1.0
34	10.0	4.8	0.8	5.0	1.0
35	10.0	5.5	0.8	10.0	1.0
36	10.0	5.5	0.8	20.0	1.0
37	12.0	5.5	0.8	15.0	2.0
38	12.0	5.5	0.8	5.0	2.0
39	5.5	4.8	0.5	5.0	2.0
40	5.5	4.8	1.0	5.0	2.0
41	10.0	4.8	1.0	3.0	1.0
42	10.0	4.8	1.0	3.0	1.0
43	10.0	4.8	1.0	3.0	1.0
44	10.0	5.5	1.0	3.0	1.0
45	10.0	5.5	0.7	3.0	1.0
46	12.0	8.0	0.7	3.0	1.0
47	12.0	8.0	0.7	3.0	1.0
48	12.0	8.0	0.7	7.0	2.0
49	12.0	8.0	0.5	3.0	1.0

Table A11: Kinetic Coefficients use in the Calibration and Verification of the MREM

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	0.03 *day* -1 at 20^o C
temperature coefficient	K1RT	1.045
Nonpredatory phytoplankton death rate	K1D	0.01 *day* -1
Phytophankton Stoichometry		
Oxygen-to-carbon ratio	ORCB	2.67 $mg\ O_2 / mg\ C$
Carbon-to-chlorophyll ratio	CCHL	30
Nitrogen-to-carbon ratio	NCRB	0.25 *mg N/mg C*
Phosphorus-to-carbon ratio	PCRB	0.025 $mg\ PO_4\text{-}P/ mg\ C$
Half-saturation constants for phytoplankton growth		
Nitrogen	KMNG1	0.010 *mg* N / L
Phosphorus	KMPG1	0.003 *mg* P / P
Fraction of dead phytoplankton recycled to organic		
nitrogen	FON	0.9
phosphorus	FOP	0.9
Light Formulation Switch	LGHTS	1 = Smith
Saturation light intensity for phytoplankton	IS1	350. *Ly/day*
BOD deoxygenation rate	KDC	0.10 *day* -1 at 20^o C
temperature coefficient	KDT	1.05
Reaeration rate constant	k2	0.30 *day* -1 at 20^o C
Mineralization rate of dissolved organic nitrogen	K71C	0.02 *day* -1
temperature coefficient	K71T	1.08
Mineralization rate of dissolved organic phosphorus	K58C	0.15 *day* -1
temperature coefficient	K58T	1.08
Phytoplankton settling velocity		0.287 *m/day*
Inorganics settling velocity		0.00864 *m/day*

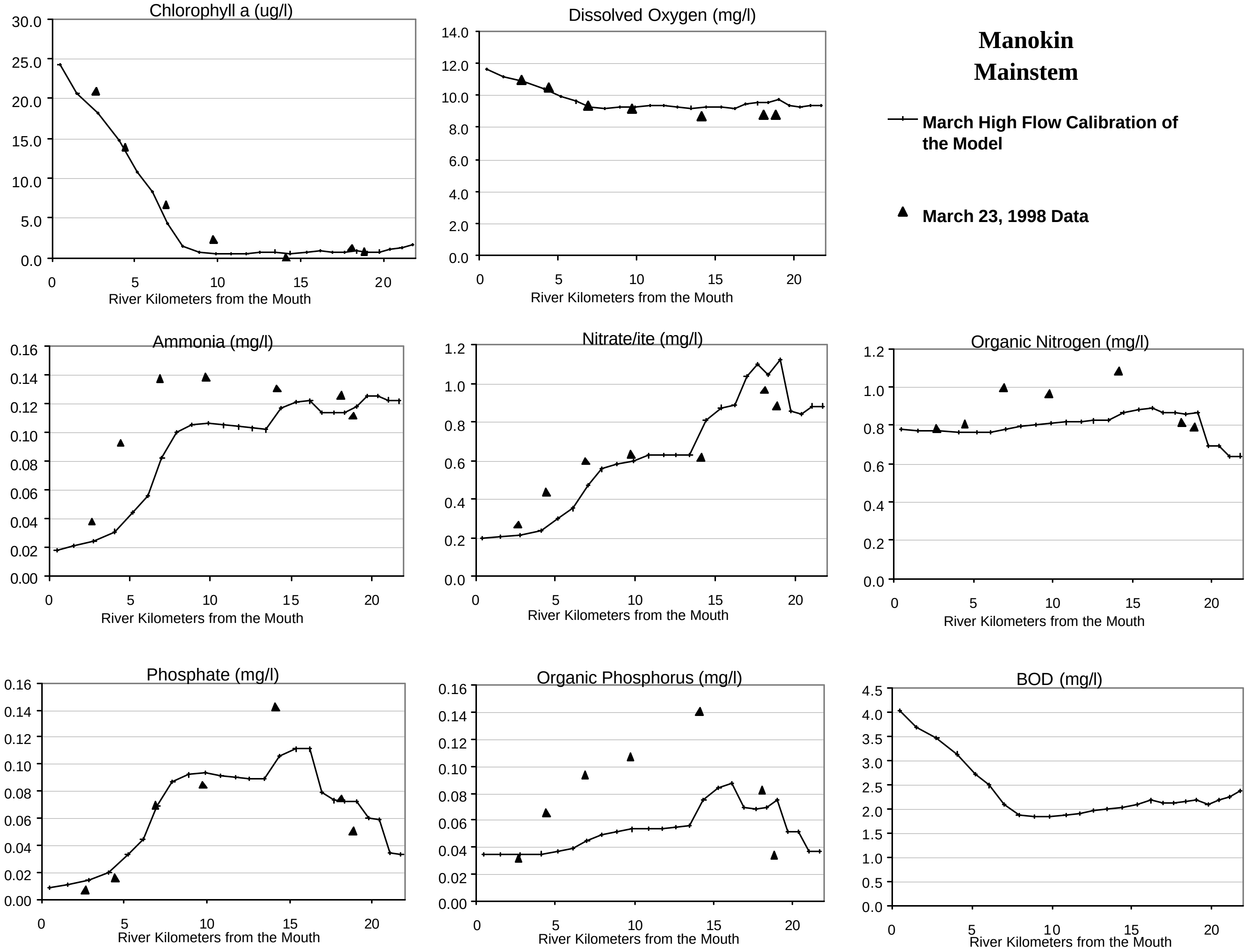


Figure A6: March High-flow Calibration of the MREM for the Mainstem of the Manokin River

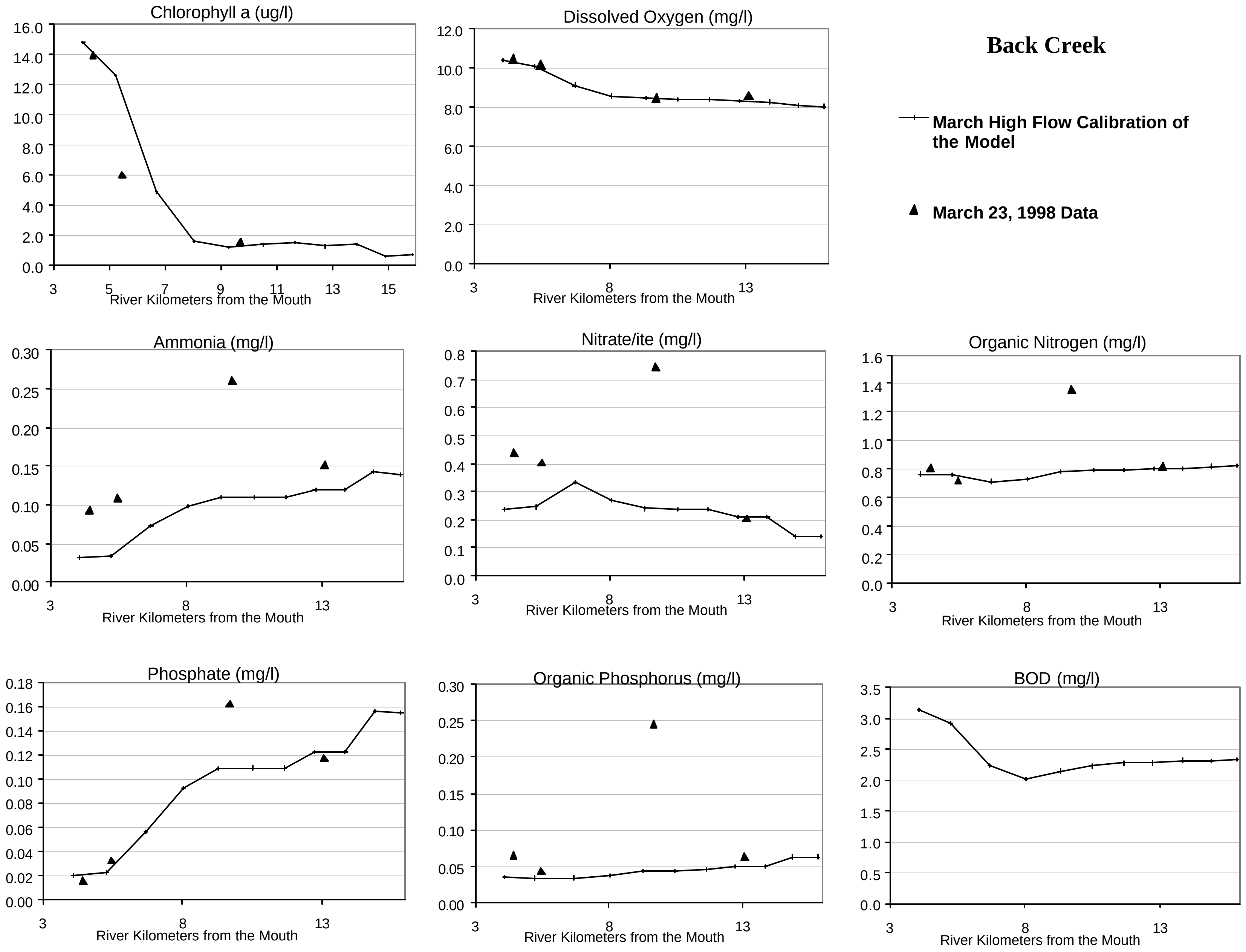


Figure A7: March High-flow Calibration of the MREM for the Back Creek Tributary

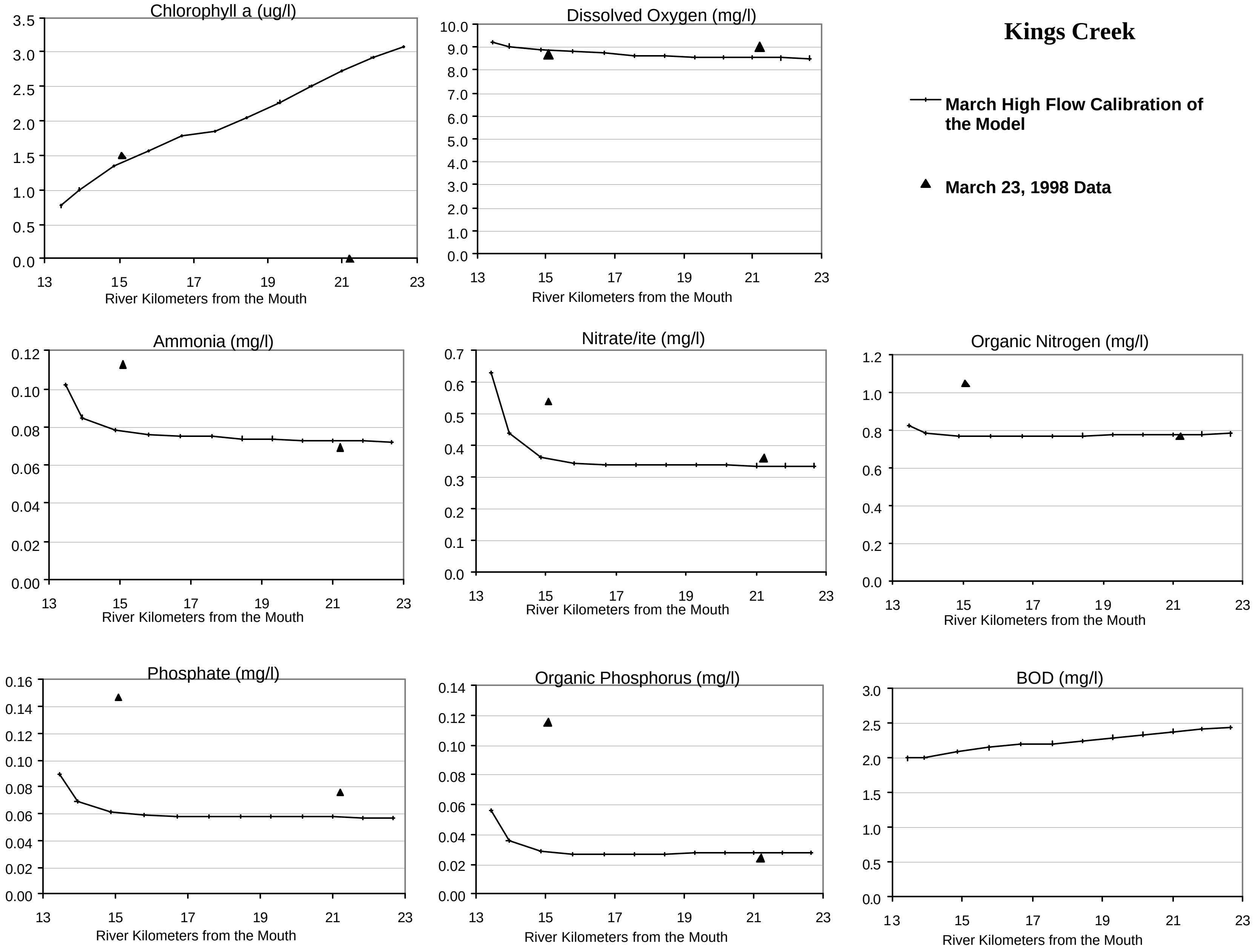


Figure A8: March High-flow Calibration of the MREM for the Kings Creek Tributary

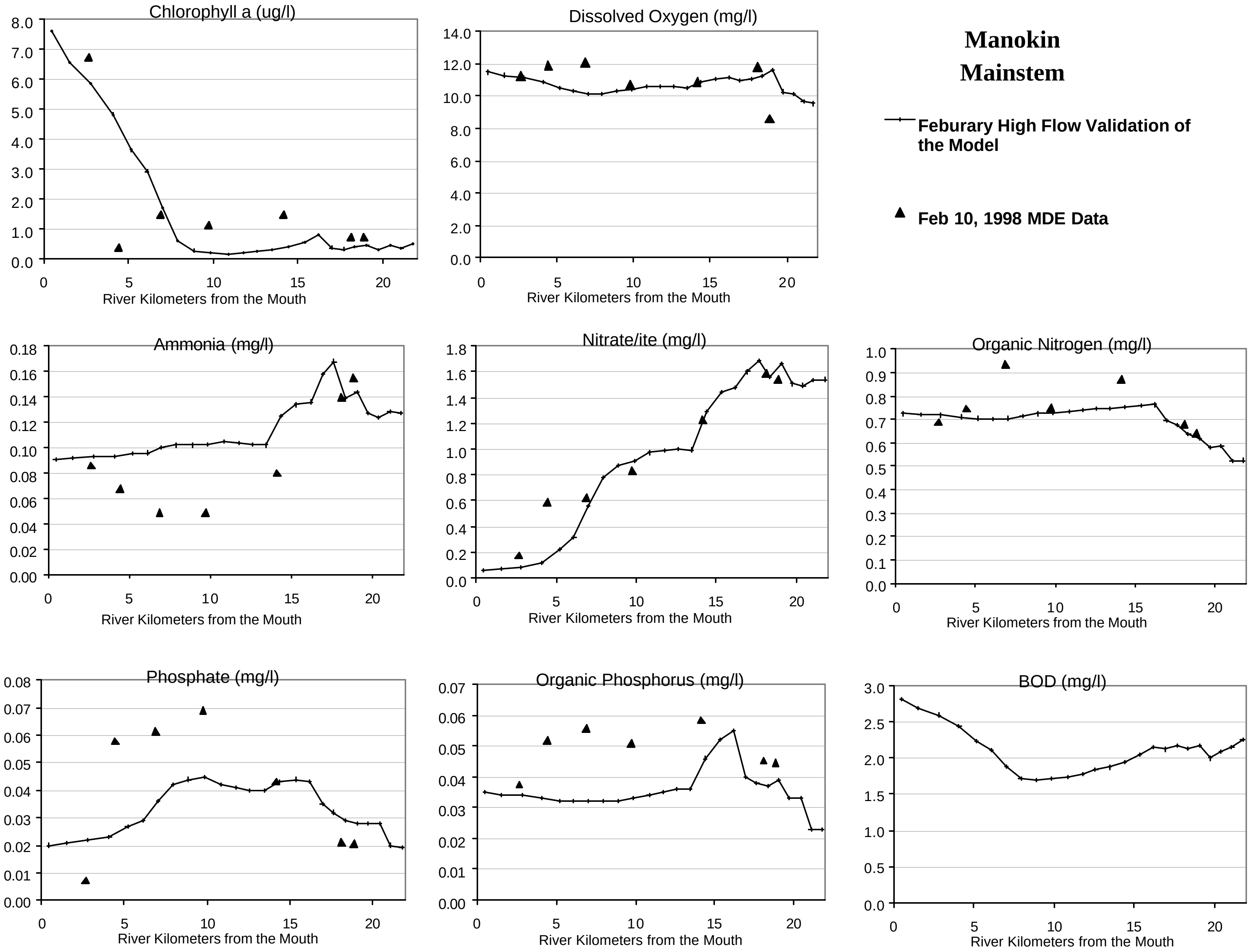


Figure A9: February High-flow Verification of the MREM for the Mainstem of the Manokin River

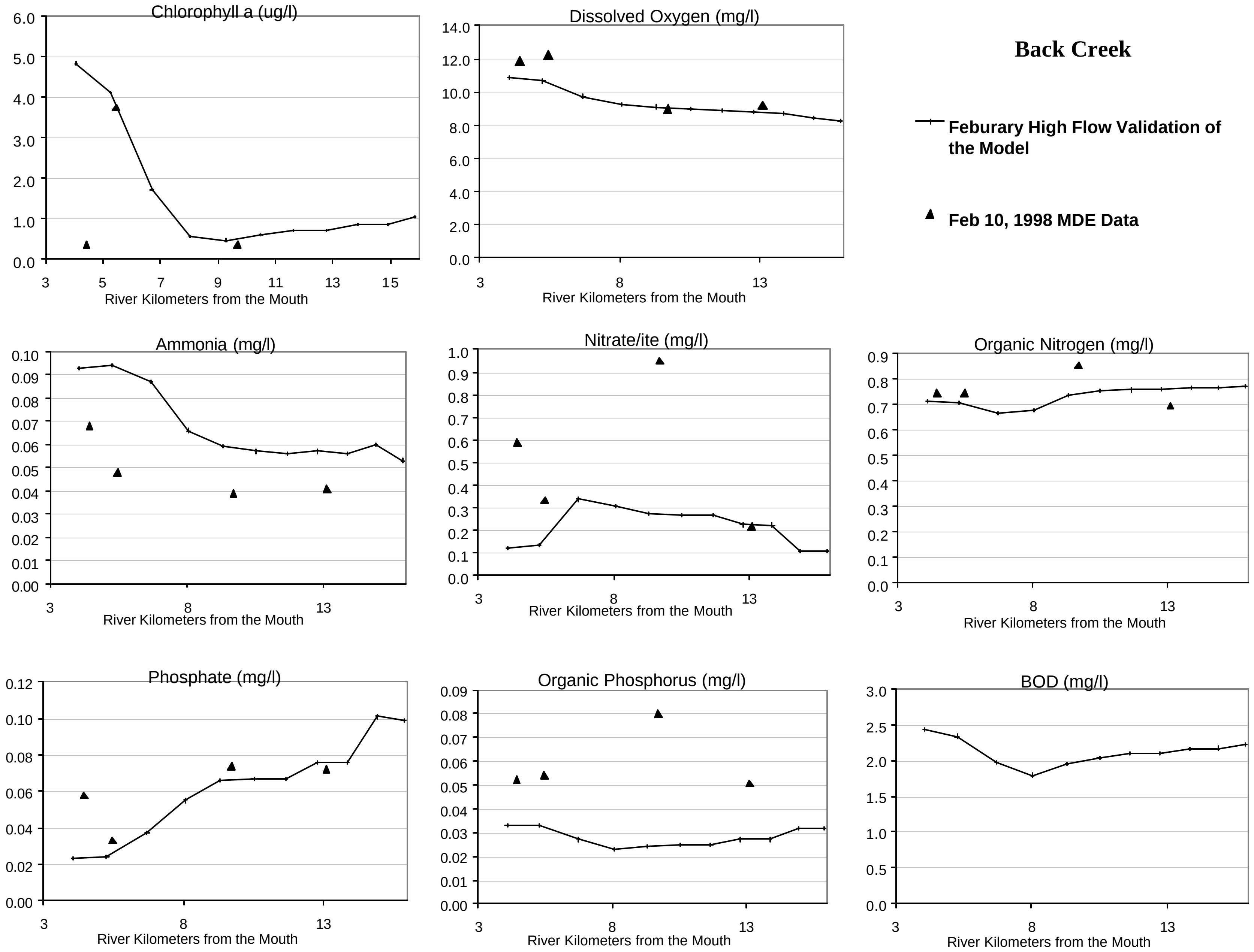


Figure A10: February High-flow Verification of the MREM for the Back Creek Tributary

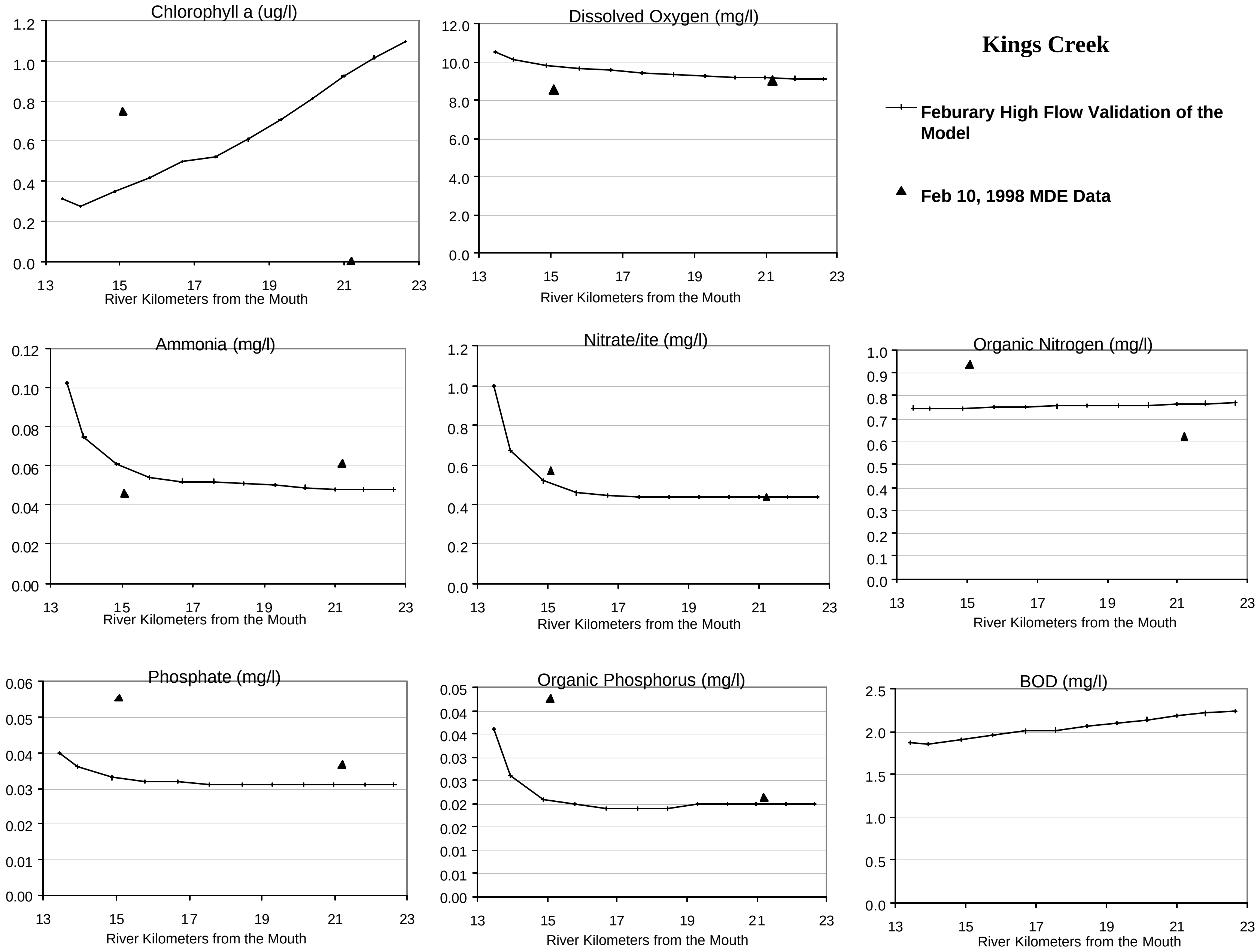


Figure A11: February High-flow Verification of the MREM for the Kings Creek Tributary

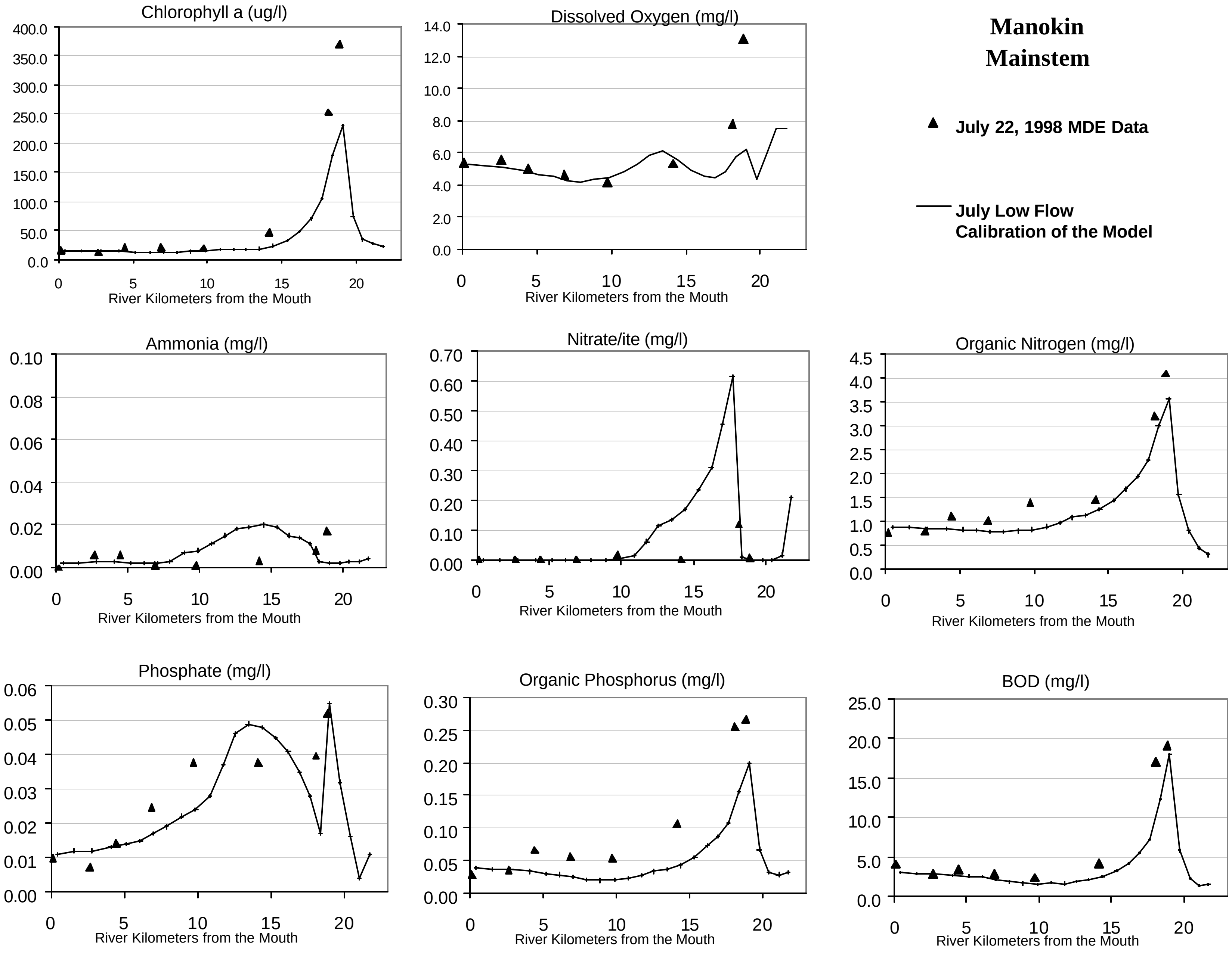


Figure A12: July Calibration of the MREM for the Mainstem of the Manokin River

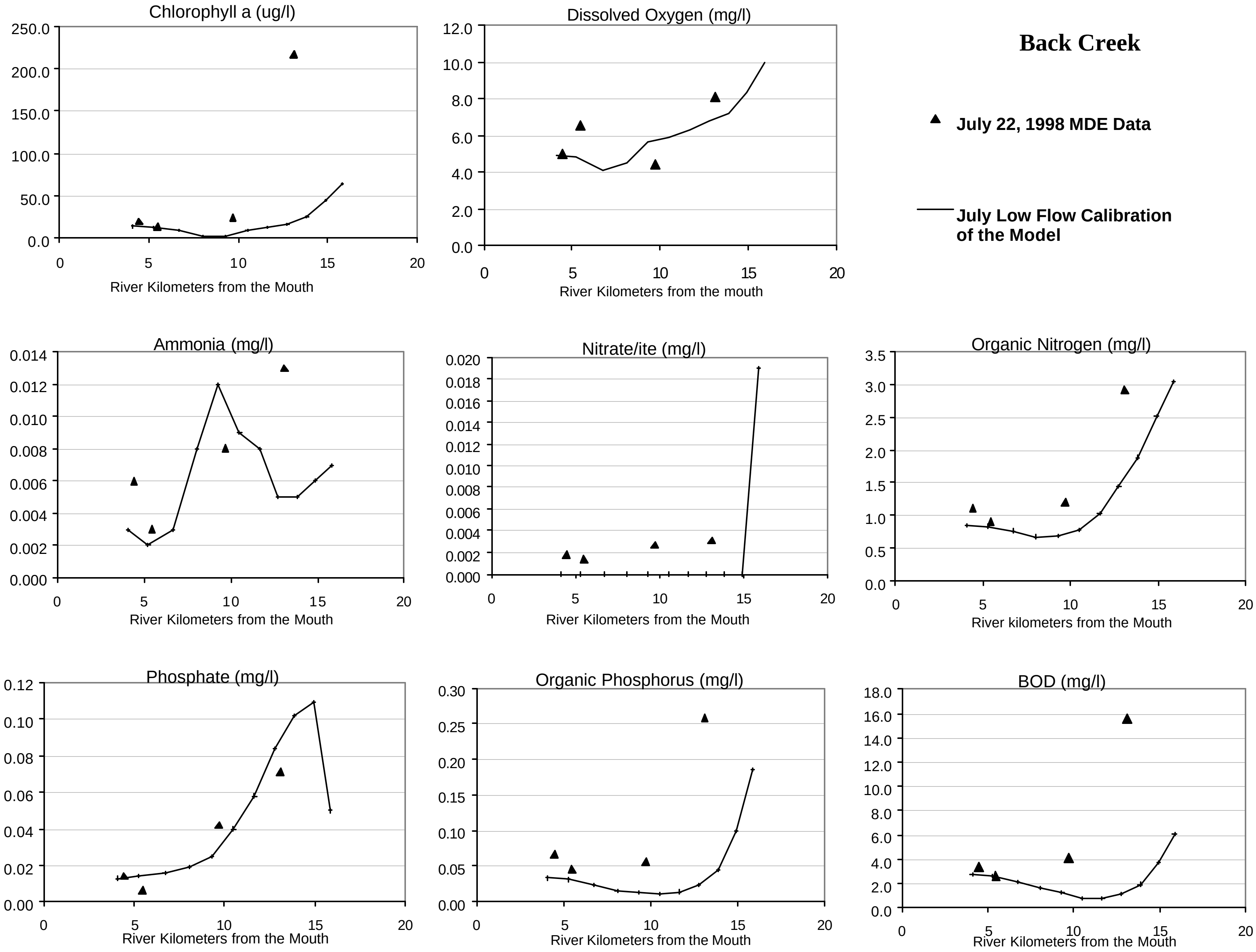


Figure A13: July Calibration of the MREM for the Back Creek Tributary

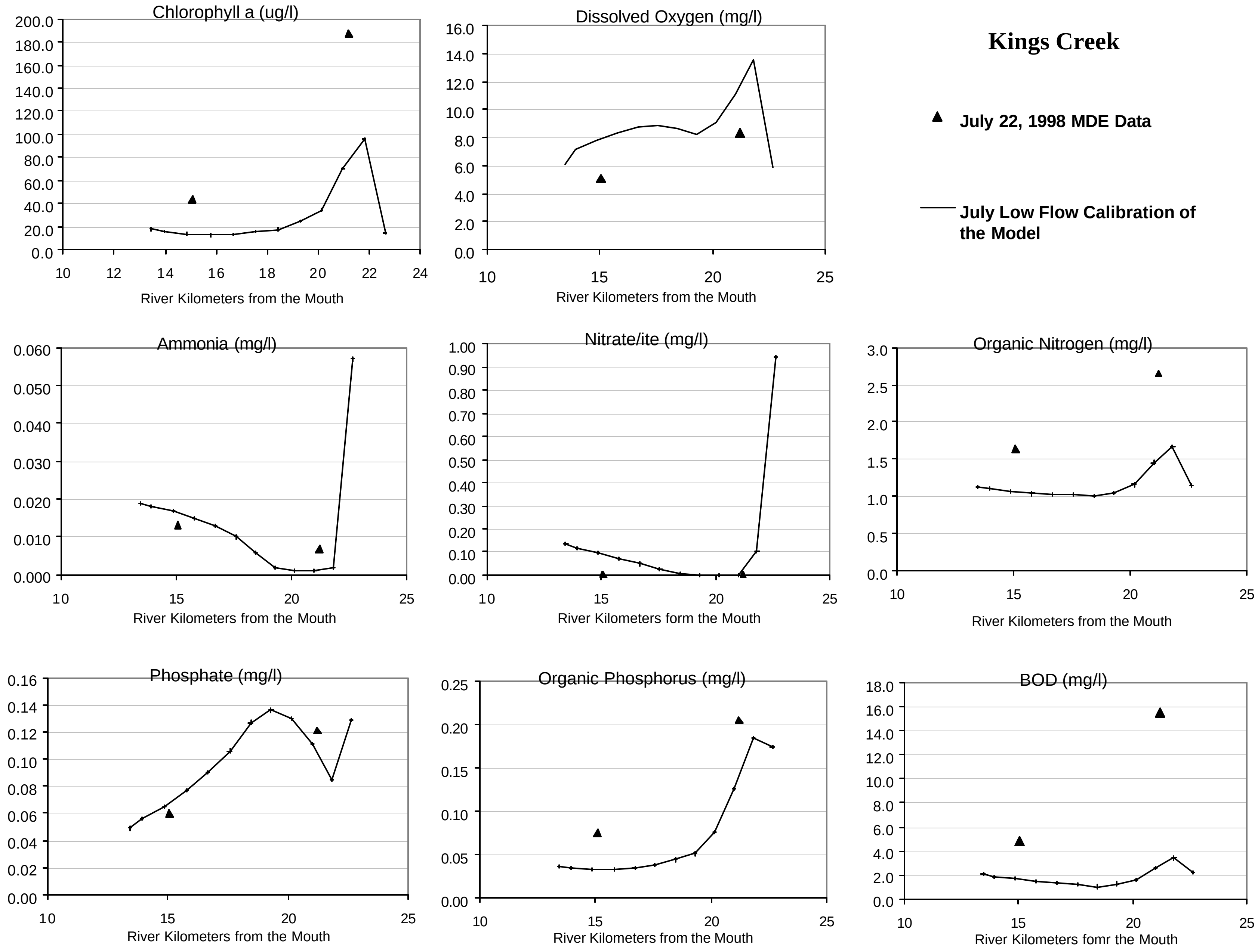


Figure A14: July Calibration of the MREM for the Kings Creek Tributary

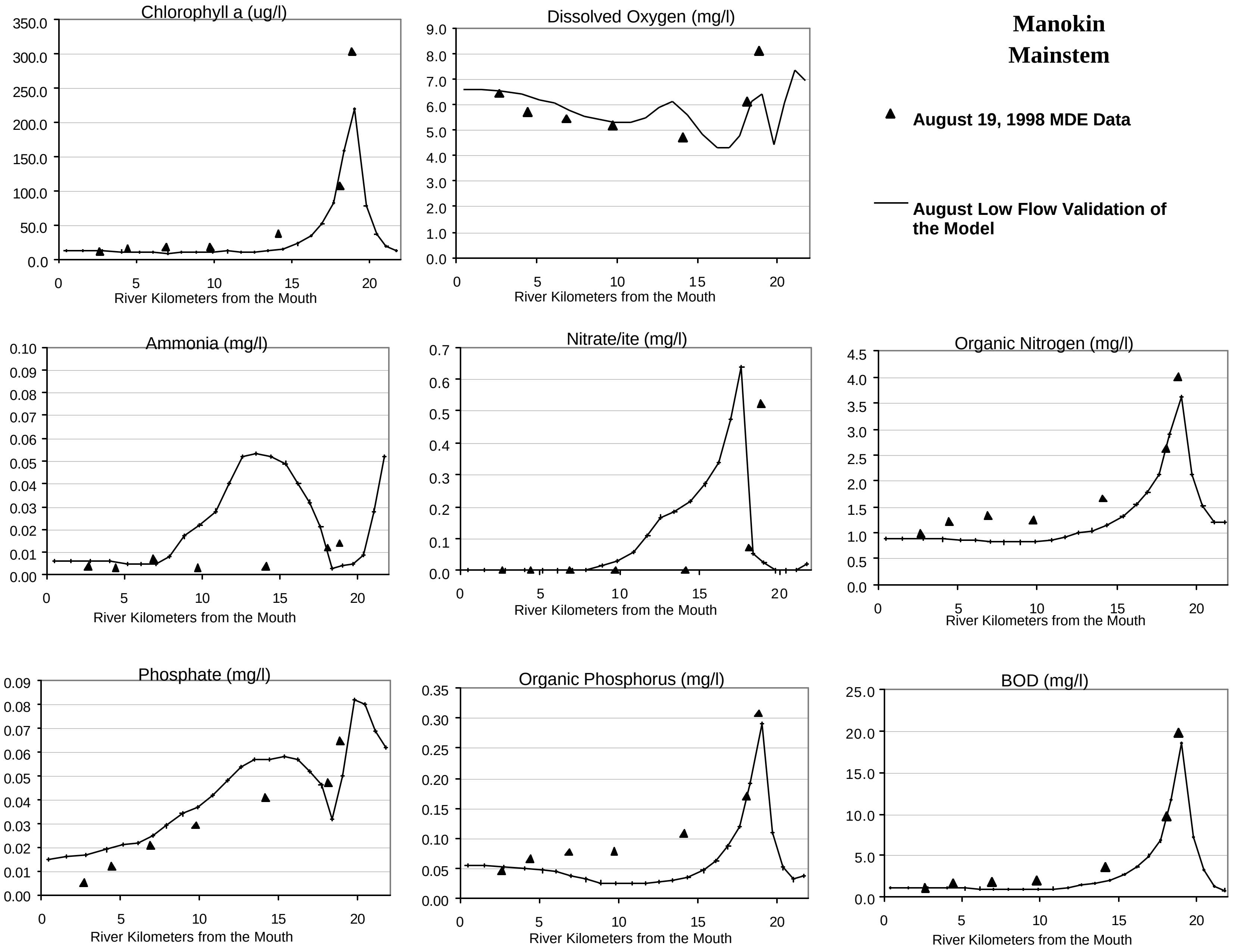


Figure A15: August Low-flow Verification of the MREM for the Mainstem of the Manokin River

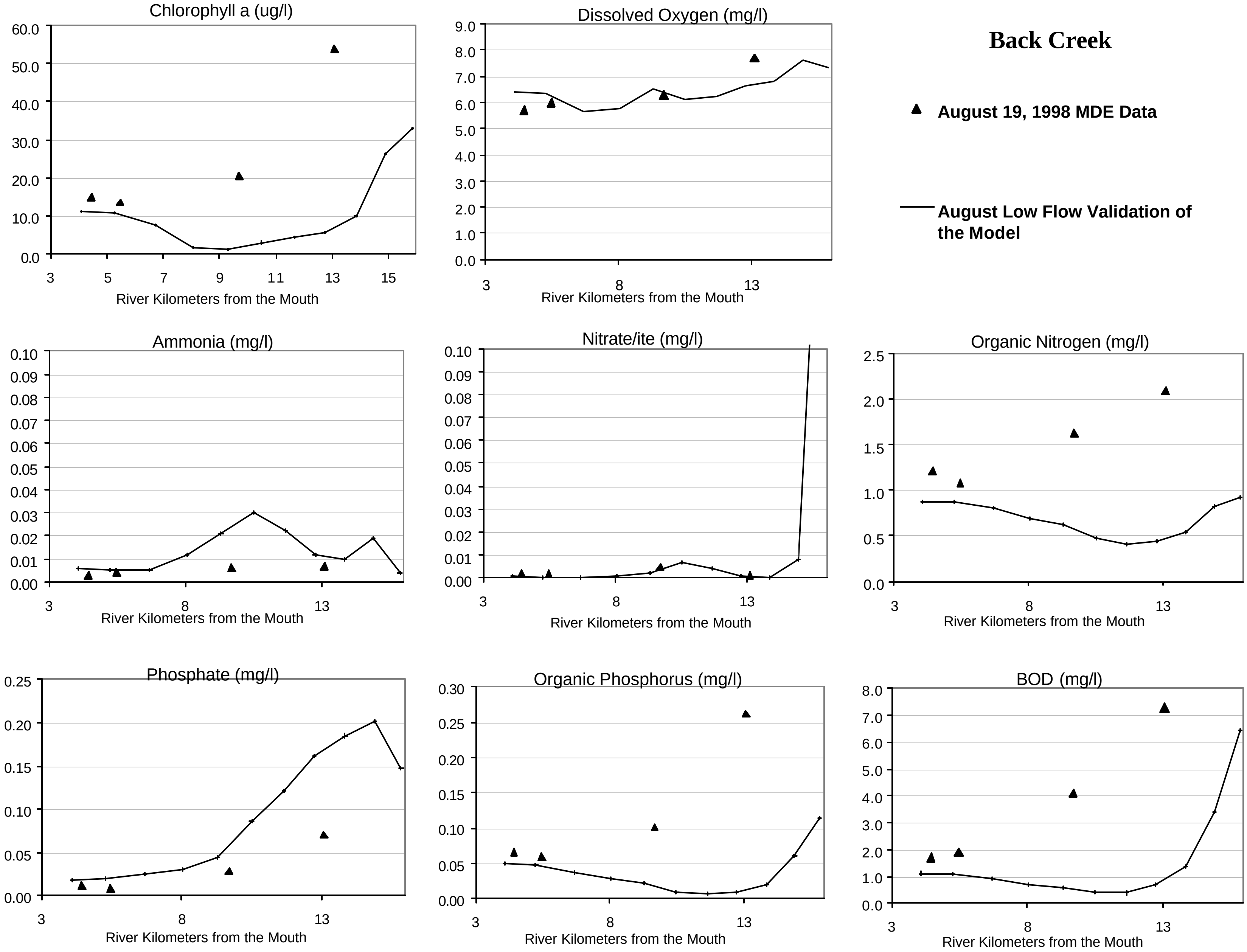


Figure A16: August Low-flow Verification of the MREM for the Back Creek Tributary

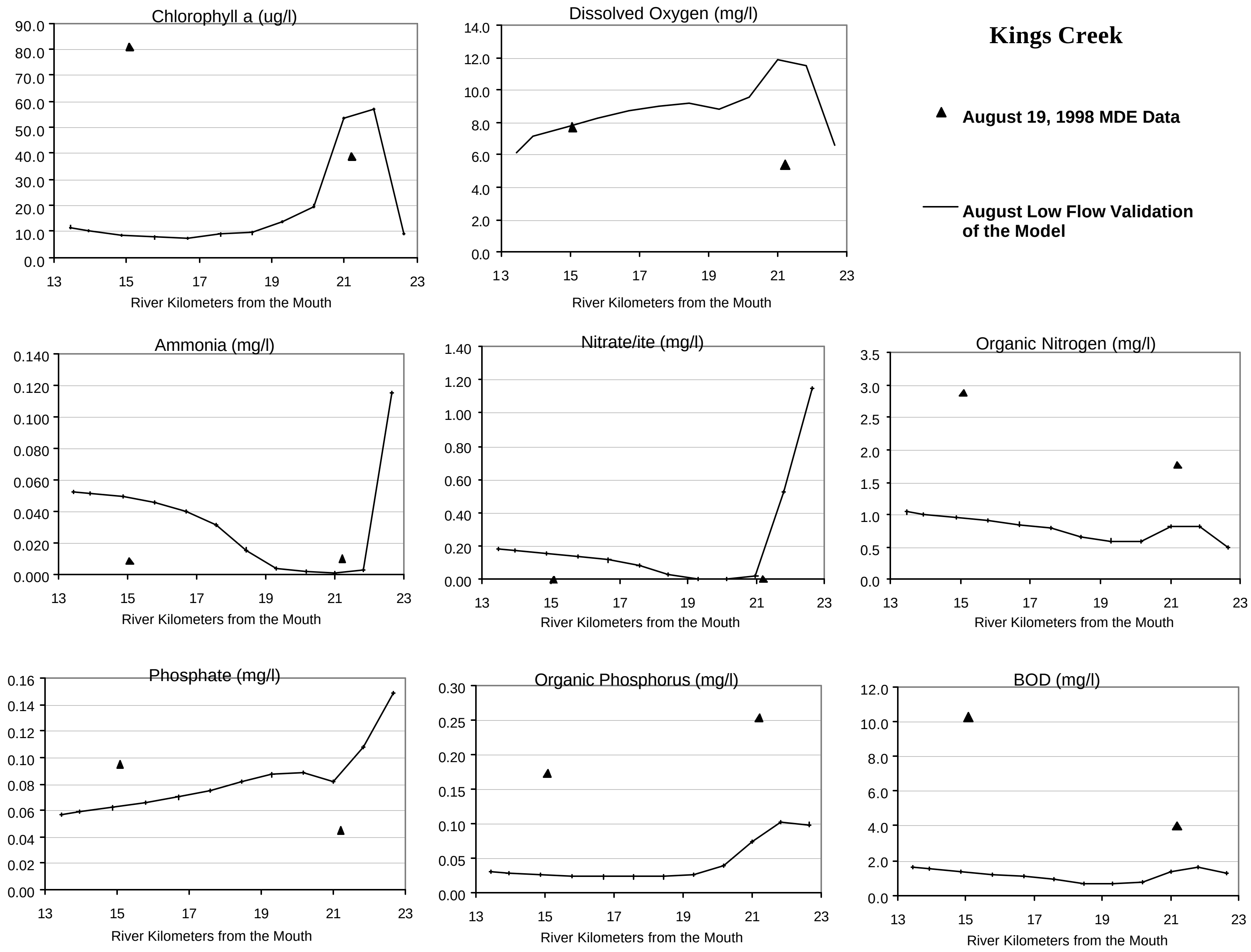


Figure A17: August Low-flow Verification of the MREM for the Kings Creek Tributary

Table A11: Low-Flow Non-point Source Nitrogen, Phosphorus, and CBOD Concentrations used in Model Scenario 1

Segment	Total Nitrogen (mg/l)	Total Phosphorus (mg/l)	CBOD (mg/l)
17	2.1	0.19	7.8
21	3.5	0.35	50.7
25	1.0	0.10	3.5
38	1.9	0.29	3.8
49	1.9	0.29	3.8

Table A12: Average-Flow Non-point Source Nitrogen, Phosphorus, and CBOD Concentrations used in Model Scenario 2

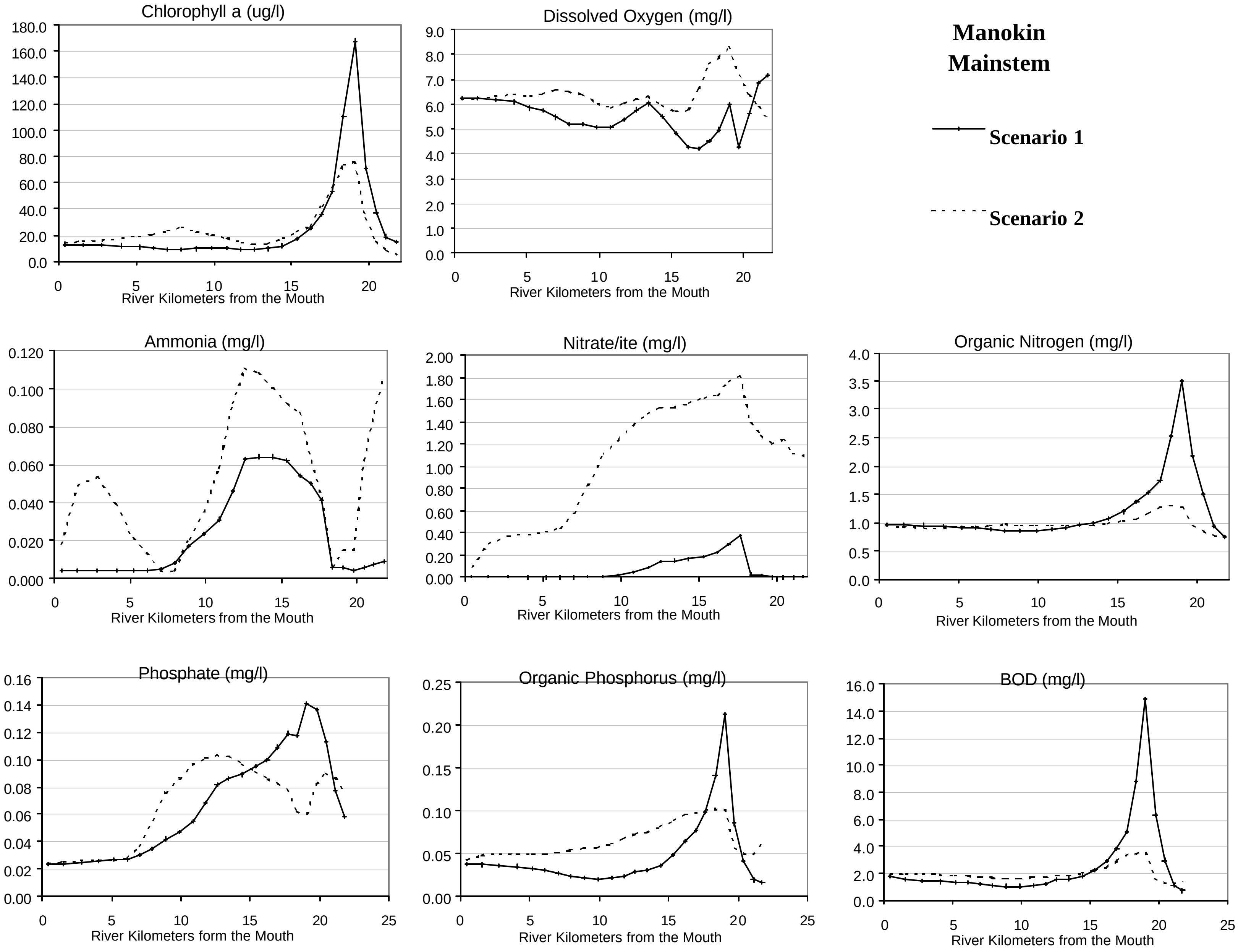
Segment	Total Nitrogen (mg/l)	Total Phosphorus (mg/l)	CBOD (mg/l)
6	5.3	0.36	3.78
9	4.3	0.30	3.78
10	2.5	0.17	3.33
14	1.8	0.14	3.78
17	2.4	0.20	3.78
18	4.1	0.26	3.78
20	3.3	0.22	3.78
21	2.2	0.13	7.8
23	3.2	0.18	3.5
25	2.0	0.14	3.5
26	1.8	0.07	4.22
27	3.2	0.16	4.22
28	2.1	0.10	4.22
29	2.6	0.17	3.5
30	2.3	0.13	3.5
31	3.3	0.27	3.33
34	3.3	0.26	3.78
36	2.7	0.19	3.78
38	2.0	0.15	3.78
40	3.0	0.22	3.78
42	3.2	0.23	3.78
47	3.2	0.28	3.78
48	2.9	0.22	3.78
49	2.2	0.17	3.78

Table A13: Low-Flow Reduced Concentrations and the Percent Load Reduction Necessary to meet Water Quality Standards

Source	Reduced Concnetrations (mg/l)	Total Load Reduction	Controllable Load Reduction
Manokin Mainstem			
Nitrogen	1.0	0%	0%
Phosphorus	0.10	0%	0%
CBOD	3.5	0%	0%
Back Creek			
Nitrogen	1.9	0%	0%
Phosphorus	0.29	0%	0%
CBOD	3.8	0%	0%
King's Creek			
Nitrogen	1.7	10%	13%
Phosphorus	0.29	0%	0%
CBOD	3.8	0%	0%
Taylor Branch			
Nitrogen	2.1	0%	0%
Phosphorus	0.19	0%	0%
CBOD	7.8	0%	0%
Loretto Branch			
Nitrogen	2.2	36%	51%
Phosphorus	0.35	0%	0%
CBOD	34.0	33%	33%
Overall			
Total Nitrogen		**18%**	**24%**
Total Phosphorus		**0%**	**0%**
Total CBOD		**26%**	**26%**

Table A14: Average-Flow Reduced Concentrations and the Percent Load Reduction Necessary to meet Water Quality Standards

Segment	Nitrogen		
	Reduced Concentration (mg/l)	Total Load Reduction	Controllable Load Reduction
6	4.4	18%	33%
9	3.6	16%	33%
10	2.0	20%	33%
14	1.3	27%	33%
17	1.8	24%	33%
18	3.1	24%	33%
20	2.5	24%	33%
21	1.8	22%	33%
23	2.6	20%	33%
25	1.5	22%	33%
26	1.8	4%	33%
27	3.2	1%	33%
28	2.0	5%	33%
29	2.2	16%	33%
30	1.9	14%	33%
31	2.4	29%	33%
34	2.4	28%	33%
36	2.1	23%	33%
38	1.5	25%	33%
40	2.2	25%	33%
42	2.5	24%	33%
47	2.3	29%	33%
48	2.1	28%	33%
49	1.6	26%	33%
Total		**21%**	**33%**


Chlorophyll a (ug/l)

Dissolved Oxygen (mg/l)

Manokin Mainstem

Ammonia (mg/l)

Nitrate/ite (mg/l)

Organic Nitrogen (mg/l)

Phosphate (mg/l)

Organic Phosphorus (mg/l)

BOD (mg/l)

Figure A18: Model Results for Scenarios 1 and 2 for the Mainstem of the Manokin River

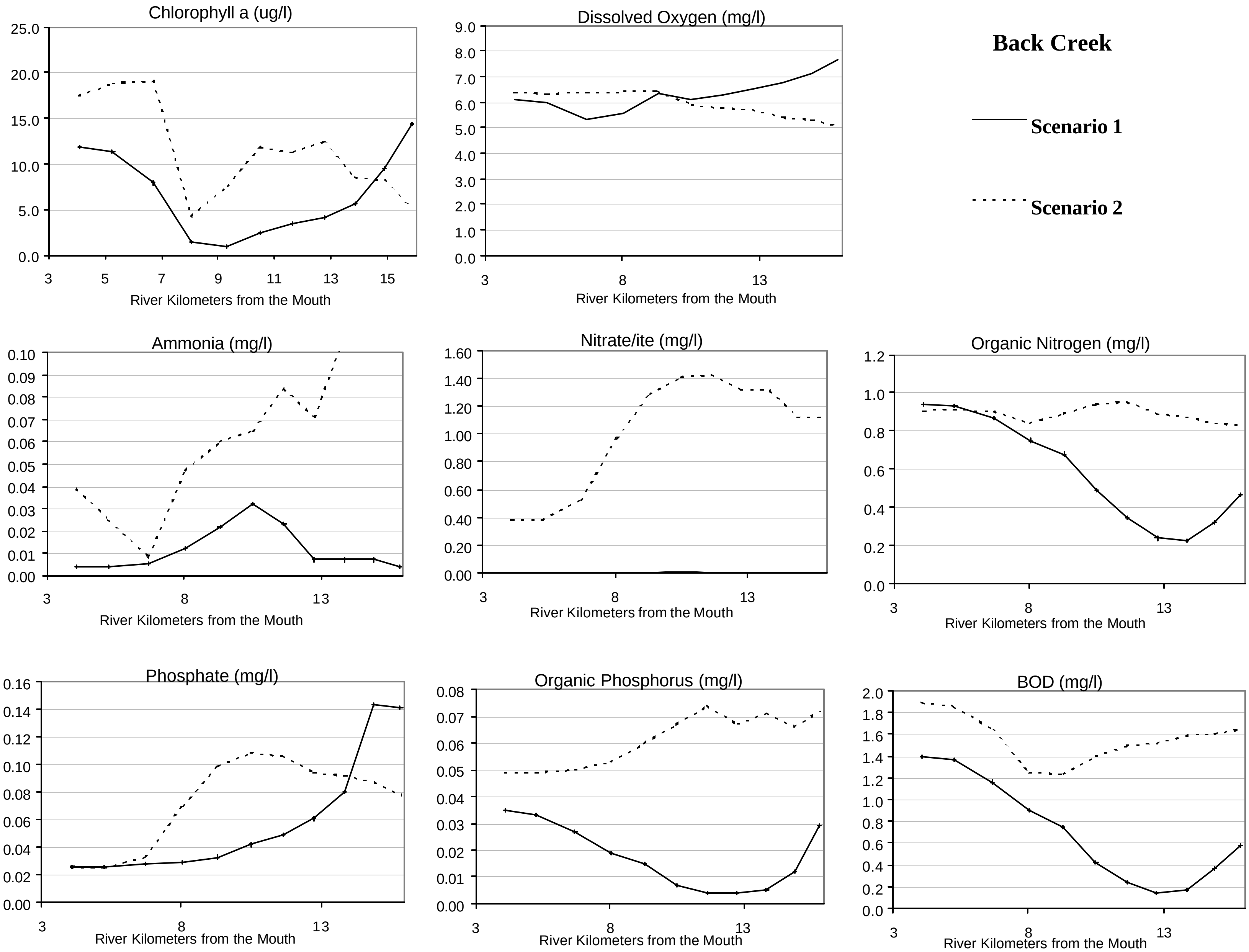


Figure A19: Model Results for Scenarios 1 and 2 for the Back Creek Tributary

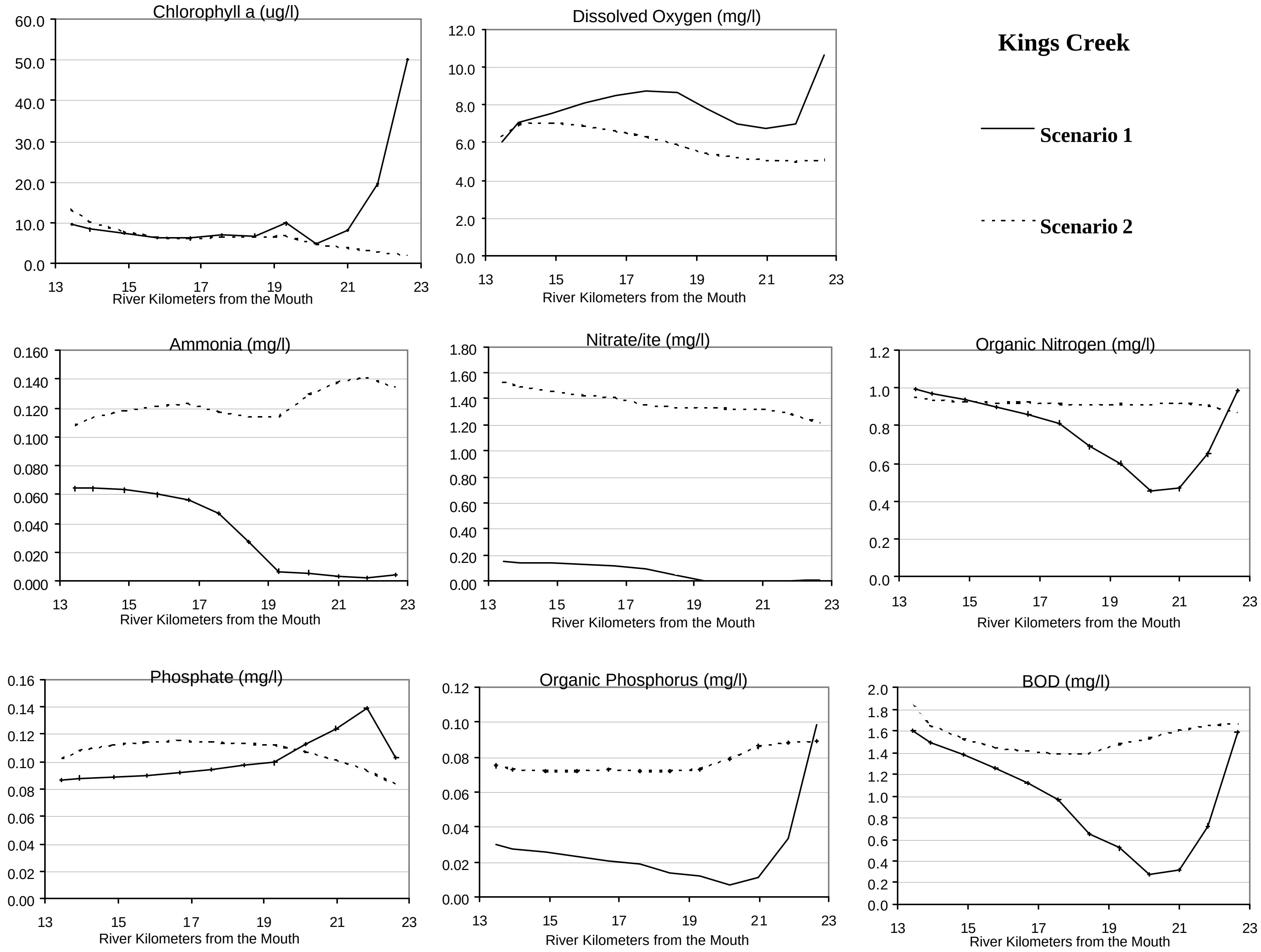


Figure A20: Model Results for Scenarios 1 and 2 for the Kings Creek Tributary

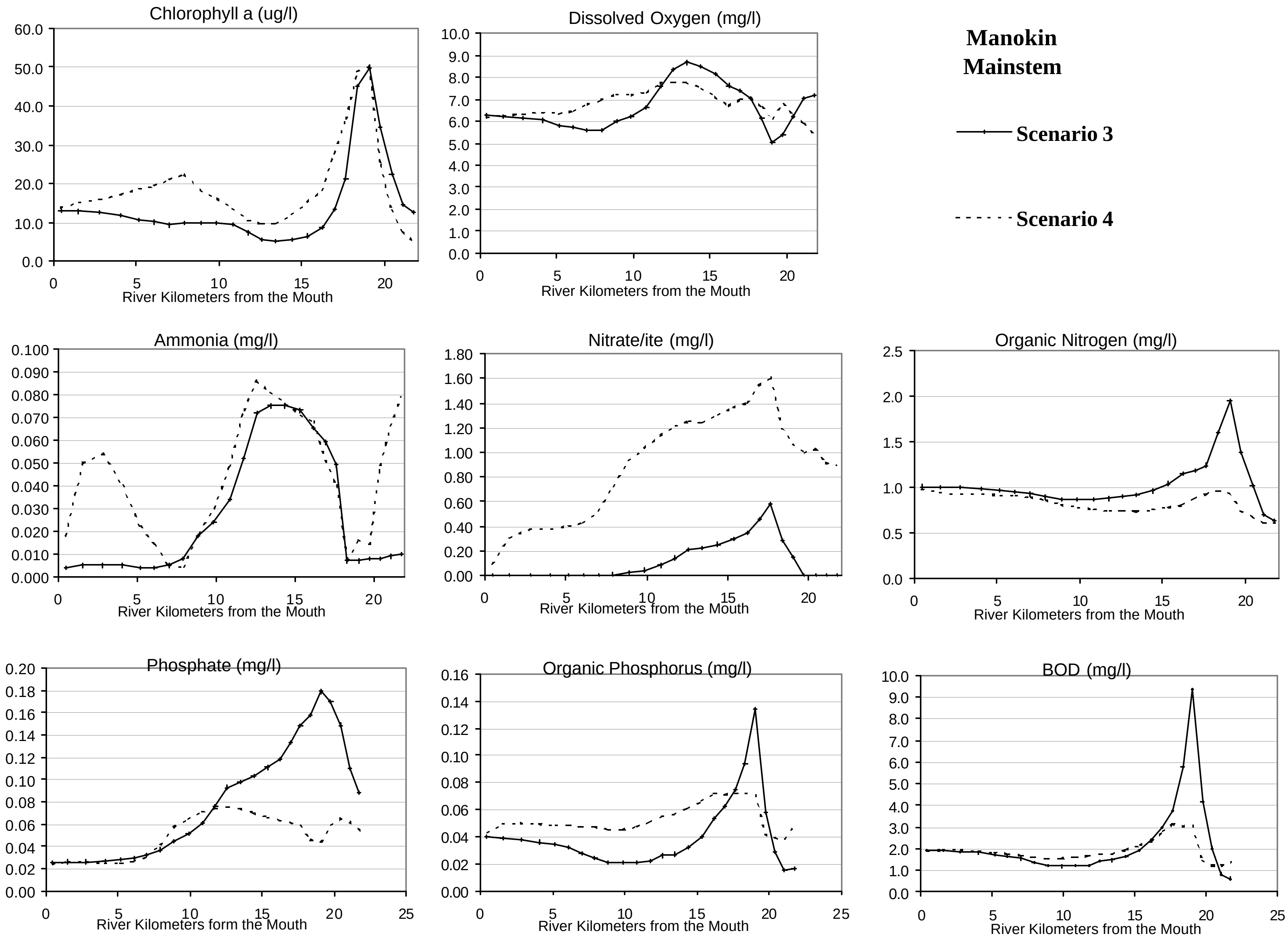


Figure A21: Model Results for Scenarios 3 and 4 for the Mainstem of the Manokin River

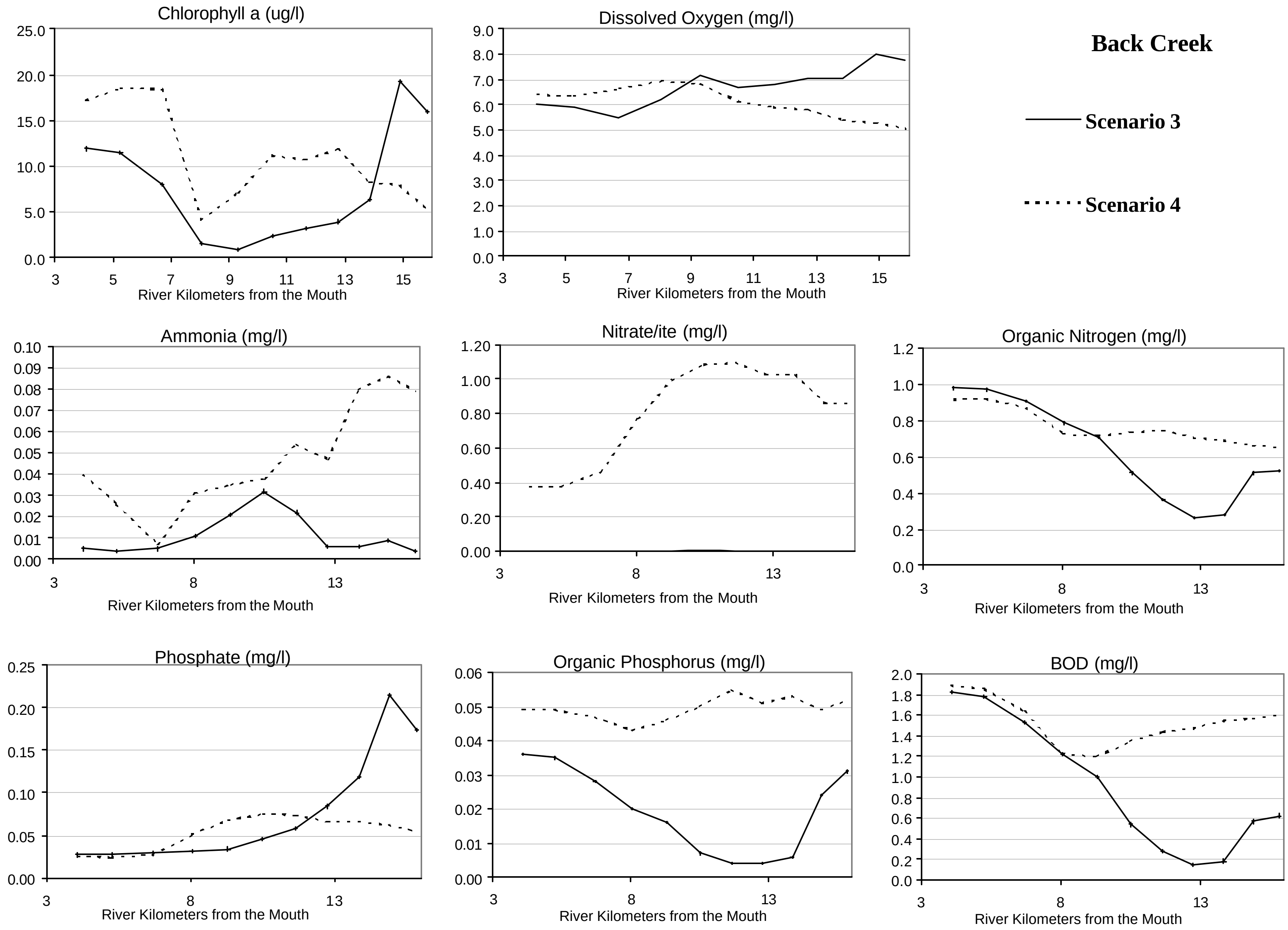


Figure A22: Model Results for Scenarios 3 and 4 for the Back Creek Tributary

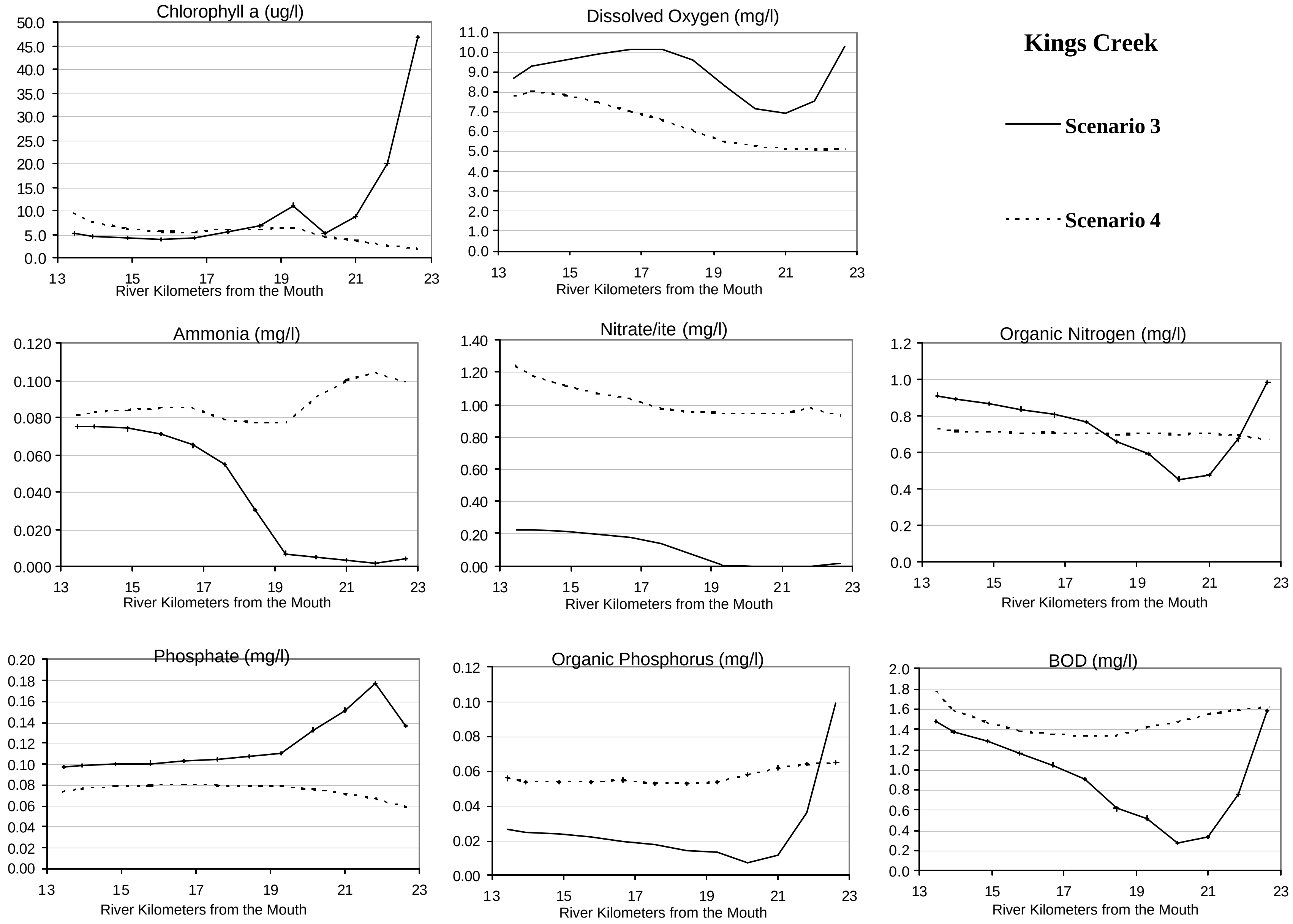


Figure A23: Model Results for Scenarios 3 and 4 for the Kings Creek Tributary

REFERENCES

Ambrose, Robert B., Tim A. Wool, John P. Connolly, Robert W. Schanz. *WASP5, a Hydrodynamic and Water Quality Model: Model Theory, User's Manual, and Programmer's Guide*. Environmental Research Laboratory, Office of Research and Development, EPA 600/3-87/039, Athens, GA. 1993.

Cerco, Carl F. *Water Quality in a Virginia Potomac Embayment: Gunston Cove.* College of William and Mary, Virginia Institute of Marine Science, Glouster Point, Virginia. April 1985.

Clark L. J., and S. E. Roesh, *Assessment of 1977 Water Quality Conditions in the Upper Potomac Estuary*. U.S. EPA Annapolis Field Office, Annapolis Maryland. EPA 903/9-78-008, 1978.

Di Toro, D.M., J.J. Fitzpatrick, and R.V. Thomann. *Documentation for Water Quality Analysis Simulation Program (WASP) and Model Verification Program (MVP).* EPA/600/3-81-044. 1983.

Domotor, Diana K., Michael S. Haire, Narendra N. Panday, and Harry V. Wang. *Mattawoman Creek Water Quality Model*. Technical Report No. 64, Maryland Department of the Environment, Water Management Administration, Modeling and Analysis Division. October 1987.

Lung, W. S. *Water Quality Modeling of the Patuxent Estuary*. Final Report to the Maryland Department of the Environment, Water Management Administration, Chesapeake Bay and Special Projects Program, Baltimore, MD. 1993.

Haire, M. S., and N. N. Panday, "Quality Assurance/ Quality Control Plan: Water Quality Assessment of the Mattawoman Creek and nearby Potomac Estuary," Office of Environmental Programs, State of Maryland, April 1985.

HydroQual, Inc. *Calibration and verification of a Mathematical Model of the Eutrophication of the Potomac Estuary*. HydroQual Inc. Final Report Prepared for D.C. Department of Environmental Services. 1982.

Maryland Department of the Environment, Maryland Point Source Database, September, 1999.

Panday, Narendra N., and Michael S. Haire. *Water Quality Assessment of Mattawoman Creek and the Adjacent Potomac River: Summer 1985.* Technical Report No. 52, Water Management Administration, Modeling and Analysis Division, Maryland Office of Programs, Department of Health and Mental Hygiene. September 1986.

Thomann, Robert V., John A. Mueller. *Principles of Surface Water Quality Modeling and Control.*

HarperCollins Publisher Inc., New York, 1987.

Thomann R. V., and J. J. Fitzpatrick. *Calibration and Verification of a Mathematical Model of the Eutrophication of the Potomac Estuary*. HydroQual, Inc. Final Report Prepared for the D.C. Department of Environmental Services, 1982.

U.S. EPA. *Technical Support Document for Water Quality-based toxics Control.* OW/OWEP and OWRS, Washington, D.C., April 23,1991.

U.S. EPA Chesapeake Bay Program. *Chesapeake Bay Program: Watershed Model Application to Calculate Bay Nutrient Loadings: Final Findings and Recommendations*. and Appendicies, May, 1996.