Appendix A

STUDY AREA

The Fairlee Creek, is located in Kent County, Maryland (Figure A1). It drains directly to the Chesapeake Bay roughly three miles due east of Pooles Island. The Creek is approximately 8.4 kilometers (km) in length, from its confluence with the Bay to the upper reaches of the headwaters. The Fairlee Creek watershed has an area of approximately 34.2 km^2 or 8,470 acres. The predominant land use in the watershed, based on 1990 Maryland Office of Planning information, is mixed agriculture (22.3 km^2 or 65%), with other areas being under forest (10.3 km^2 or 30%) and urban (1.6 km^2 or 5%).

Fairlee Creek is tidal throughout its navigable reach, which extends from the highly depositional delta area at its mouth for approximately 3.5 km upstream to an area known as Goose Hollow. Above the limit of navigability of most powerboats, Fairlee Creek's mainstem bifurcates into separate branches, with one traveling due south and the other continuing along the centerline of the Creek towards the southeast. Numerous beaver dams are located on both of the upper free flowing branches. This dramatically reduces creek velocities in those branches. Depths of the river range from about 0.3 meters in the headwaters to greater than 1.5 meters in the tidal zone prior to the creek's confluence with the Chesapeake Bay.

In the Fairlee Creek watershed, the estimated total nitrogen load is 40,979 kg/yr, and the total phosphorus load is 2,974 kg/yr, for the year 1991. The existing nonpoint source loads were determined using land use loading coefficients. The land use information was based on 1990 Maryland Office of Planning data. The total nonpoint 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, 1991), which was a continuous simulation model. The Chesapeake Bay Program nutrient loading rates account for atmospheric deposition[1], loads from septic tanks, and loads coming from urban development, agriculture, and forest land. The total nitrogen load coming from nonpoint sources is 40,239 kg/yr, and the total nonpoint source phosphorus load is 2,889 kg/yr.

The point source flows came from the discharge monitoring reports stored in MDE's point source database. However, because both of the WWTPs (Wastewater Treatment Plants), Fairlee and Great Oak Landing, have such small discharges, neither are required to report nitrogen or phosphorus concentrations. So, to calculate the loads, WWTP effluent concentration were estimated using measured water quality effluent data from July and August of 1991. The July and August data was selected because it was the most reliable field data which was readily

1 Atmospheric deposition directly to the water's surface was not taken into account. The surface area of the water in the Fairlee Creek Basin only accounts for a small amount of the total surface area of the watershed. And, the majority of the water surface, the estuary, is located downstream from the impairment. Thus, the contribution from atmospheric deposition directly to the water's surface was considered insignificant.

available. When used in conjunction with the actual plant flows the estimated concentrations give a reasonable estimate of the yearly loads. The total nitrogen load coming from point sources is 740 kg/yr, and the total nitrogen point source load is 85 kg/yr. The year 1991 was used because this is the year for which all relevant water quality data was measured.

WATER QUALITY CHARACTERIZATION

The water quality of four physical parameters, chlorophyll *a*, inorganic phosphorus, ammonia, and dissolved oxygen, were examined to determine the extent of the impairment in Fairlee Creek. Four water quality surveys were conducted in the Fairlee Creek watershed in July and August of 1991. Figure A1 identifies the sampling locations during each survey. The physical and chemical samples were collected by MDE's Field Operations Program staff. The physical parameters like dissolved oxygen and water temperature were measured *in situ* at each water chemistry monitoring station. Grab samples were collected for chemical and nutrient analysis. The samples were collected at a depth of ½ m from the surface. Samples were placed in plastic bottles and preserved on ice until they were delivered to the Department of Health and Mental Hygiene in Baltimore, MD for chemical analysis. The field and laboratory protocols used to collect and process the samples are also described in Table A1. The July and August 1991 data was used to calibrate the model employed in determining the TMDL.

Figure A2 presents a longitudinal profile of chlorophyll *a* data sampled during the 1991 field surveys. The sampling region covers the entire tidal portion of the Fairlee Creek from its confluence with the Chesapeake Bay (Station FRL-13), and includes free-flowing stations in the southeast tributary leading up to and above the Fairlee WWTP. Table A2 states the location (in km from Fairlee Creek's mouth) of all the water quality stations. As the data indicates, ambient chlorophyll *a* concentrations for the first 4 km are all below 50 µg/l. However, the levels are much greater above 4 km, where mean values are about 80 µg/l, with a maximum concentration of over 200 µg/l.

Dissolved oxygen concentrations along the longitudinal profile are depicted in Figure A3. As the data indicates, above station FRL-7 (4.220 km) the dissolved oxygen levels fall below the standard of 5 mg/l. In the tidal portion of the creek, dissolved oxygen concentrations are well above the standard.

The ammonia levels along the longitudinal profile are depicted in Figure A4. In the tidal portion of Fairlee Creek, ammonia levels are generally less than 0.05 mg/l. However, the concentration of ammonia increases rapidly in the free-flowing southeast tributary, with peak values in the immediate vicinity of the Fairlee WWTP outfall exceeding 0.2 mg/l at station FRL-5.

Figure A5 presents a longitudinal profile of inorganic phosphorus as indicated by ortho-phosphate levels measured in samples collected in 1991. They are similar to that of ammonia, with concentrations in the tidal portion measured at or near the level of detection (0.01 mg/l), with elevated levels near the outfall of the Fairlee WWTP with a maximum concentration of greater than 0.09 mg/l.

MODELING FRAMEWORK

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

WASP5 is supported and distributed by U.S. EPA's Center for Exposure Assessment Modeling (CEAM) in Athens, GA (Ambrose *et al.*, 1988). EUTRO5 is the component of WASP5 that is applicable of modeling eutrophication, incorporating eight water quality constituents in the water column (Figure A6) and sediment bed. EUTRO5 is used to develop the water quality model of Fairlee Creek system.

INPUT REQUIREMENTS [2]

Model Segmentation and Geometry

The spatial domain of the Fairlee Creek Eutrophication Model (FCEM) extends from the confluence of the Fairlee Creek and the Chesapeake Bay for about 5.5 km along the mainstem and southeast tributary of Fairlee Creek. Following a review of the bathymetry for Fairlee Creek, the model was divided into 18 segments. Figure A7 shows the model segmentation and the location of the WWTPs. Table A3 lists the volumes, characteristic lengths and interfacial areas of the 18 segments. Initial exchange coefficients were obtained from previous modeling of Fairlee Creek River and adjusted during the calibration of the model. Final values were 0.001m^2/day for segments 10 through 13 and 18; 0.03 m^2/day for segment 16; 1.2 m^2/day for segments 14, 15, and 17; 1.3 m^2/day for segments 5 through 9; 2.3 m^2/day for segments 1 through 4. Freshwater flows and nonpoint source loadings are taken into consideration by dividing the drainage basin into 6 subwatersheds and assuming that these flows and loadings are direct inputs to the FCEM (Figure A7 and Table A4).

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

Freshwater Flows

The low and average flows for the 6 subwatersheds in Fairlee Creek basin were estimated using a nearby United States Geological Survey (USGS) flow gage. The USGS gage at Morgan Creek (01493500) was used because it is located nearby and assumed to have similar drainage characteristics, and because it had a similar drainage area size. The ratio of flow to drainage area in Morgan Creek was multiplied by the area of each of the six subwatersheds, to obtain the flow in Fairlee Creek. The 7-day consecutive lowest flow expected to occur every 10 years, known as the 7Q10 flow seven, for Morgan Creek was 1.5 cfs. The yearly average flow was 10.6 cfs.

Point and Nonpoint Source Loadings

There are two point source nutrient loads that discharge directly or indirectly into Fairlee Creek. The Great Oak Landing WWTP discharges into a tributary of Fairlee Creek, known as Great Oak Landing Cove. The Fairlee WWTP discharges directly into the Creek. The point source loadings used in the calibration of the model were calculated by averaging the July and August 1991 data for each WWTP (Table A5).

The nonpoint source loadings for the calibration of the model were calculated using data from five water quality stations within Fairlee Creek Basin. Station FRL-1 was used as a boundary condition for segment 1; station FRL-1 was used as a boundary condition for segments 14 and 15; station FRL-6 was used as a boundary condition for segment 17; station FRL-2 was used as a boundary condition for segment 18; and station FRL-4 was used as a boundary condition for segment 13 (Table A6). The nonpoint source loads reflect atmospheric deposition, loads coming from septic tanks, loads coming from urban development, agriculture, and forest land.

For both point and nonpoint sources, the concentrations of the nutrients nitrogen and phosphorus are modeled in their speciated forms. The WASP5 model simulates nitrogen as ammonia (NH_3), nitrate 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

For application to Fairlee Creek River eight environmental parameters were used for solar radiation, photoperiod, temperature (T), extinction coefficient (K_e), salinity, sediment oxygen demand (SOD), sediment ammonia flux (FNH_4), and sediment phosphate flux (FPO_4) (Table A7).

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 3.45 *m/day*. In general, 50% of the nonliving organics were considered in the particulate form. Such assignments were borne out through model sensitivity analyses.

Numerous beaver dams are located on both of the upper free flowing branches. This dramatically reduces creek velocities in those branches, allowing more phytoplankton to settle. The WASP model dose not easily allow segment specific settling velocities. The modeling framework was used to permit greater settling of phytoplankton in the upper reaches where the water is moving slower, and less settling in the lower tidal reaches with higher velocities. For the lower tidal segments, 97% of the phytoplankton was considered dissolved. This allowed for less settling. A phytoplankton settling rate velocity of 0.0432 *m/day* was used following a series of model calibration and sensitivity runs.

The SOD in the upper reaches of the Creek was higher due to the high concentrations of chlorophyll *a* which were settling out and the high inputs of nutrients and BOD from the Fairlee WWTP. A value of 4.0 $mg\ O_2/m^2day$ was used. This value is considered reasonable based on the condition of the stream and the literature (Thomann, 1987).

Kinetic Coefficients

The water column kinetic coefficients are universal constants used in the EUTRO5 model. They are formulated to characterize the kinetic interactions among the water quality constituents. The initial values were taken from past modeling studies of Potomac River (Clark and Roesh, 1978, Thomann and Fitzpatrick, 1982, 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 A8.

A CBOD deoxygenation rate of 0.3 day^{-1} at 20 ^oC was used for the calibration of the model. This is at the lower end of the range of values given by Thomann (1987), and is reasonable given the condition of the stream.

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 (35 days) it was found that initial conditions did not impact the final results.

CALIBRATION & SENSITIVITY ANALYSIS

The EUTRO5 model was calibrated with July and August 1991 data. Table A5 and Table A6 show the point and nonpoint source loads and flows associated with the calibration input file. Table A6 shows the flows at each of the boundary nodes. Figure A8 - A15 shows the results of the calibration run. As can be seen, in Figure A9 the model did a good job of capturing the trend in the dissolved oxygen data. The model did an excellent job of capturing the peak chlorophyll *a* concentrations and also the general trend (Figure A10). The model also captured the peak nitrate plus nitrite and Ortho-phosphate concentrations as well as their overall trend (Figure A11 and A15). It was able to replicate the organic nitrogen trend although it did not capture the peak values because of the spread in the data (Figure A12).

One sensitivity analysis was conducted using estimated high flows (0.885 m^3/s, 31.26 cfs) in Fairlee Creek. The results can be seen in Figure A16-A23. As can be seen the chlorophyll *a* concentrations were reduced compared to the calibration results of the model.

SYSTEM RESPONSE

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

Model Run Descriptions

The first scenario represents the base case conditions of the stream at low flow, (0.0442 m^3/s) nonpoint source flow in the basin, and warm water temperatures (above 21 ^0C). For the first scenario, the 7-day consecutive lowest flow expected to occur every 10 years, known as the 7Q10 flow, was used. The total nonpoint source (NPS) loads were computed using 1991 base-flow field data. The nonpoint source loads reflect atmospheric deposition, loads from septic tanks, and other nonpoint sources loads coming off the land. The total point source loads were actual loads measured during the 1991 water quality surveys. All the environmental parameters and kinetic coefficients used for the calibration of the model remained the same for scenario 1.

The second scenario represents the base case conditions of the stream at average flow, 11.1 cfs total flow in the basin. The total nonpoint source loads were calculated using the same methodology described in the beginning of the document for the 1991 loads**.** They were based on average loading rates that are consistent with the Chesapeake Bay Program loading rates (U.S. EPA, 1991), and account for both atmospheric deposition and loads from septic tanks. All the kinetic coefficients remained the same as for the calibration of the model. All the environmental parameters remained the same except for the temperature. The temperature was changed to a summer average of 23.5 ^{o}C for all segments. The total point source loads were average annual estimates based on the 1991 July and August field data as well as the 1991 discharge monitoring reports (DMRs). The nonpoint source loads for model scenarios 1 and 2 can be seen in Table A10. The point source loads for model scenarios 1 and 2 can be seen in Table A11.

In 1996 Fairlee WWTP stopped discharging to Fairlee Creek. No follow up data has been taken since then. Scientists in the Chesapeake Bay Program believe that the sediments have a short memory, and conditions in a system will improve after loadings are reduced. It was also assumed that some of the environmental parameters and kinetic coefficients would change in the near future after the load from Fairlee WWTP had been removed. For scenarios 3 and 4 several changes in the model parameters and kinetic coefficients were assumed. It was assumed that the SOD rate would decrease in the upper reach to the same rate as in the lower reaches, 0.40 $g\ O_2/m^2 day$. It was also assumed that the nutrient fluxes from the sediment would decrease to 10 $mg\ NH_4\_N/m^2 day$ and 1.0 $mg\ PO_4\_P/m^2 day$ for the upper reaches (segments 10-13, 18). Finally the CBOD deoxygenation rate would also decrease from 0.3 day^{-1} to 0.1 day^{-1}.

In the next two scenarios, the model was used to predict the water quality response in the Creek without the Fairlee WWTP discharging to see if a water quality violation was still occurring. The third scenario represented the future conditions, without the Fairlee WWTP, for the case of low stream flow. The total nonpoint source flows were the same as for scenario 1. Nonpoint source loads were simulated as 1991 summer base flow nutrient concentrations plus a 3% margin of safety (MOS). The 1991 base flow nonpoint source loading was selected because it was the most reliable field data which was readily available. Because the 1991 loads represent base-flow loads attributable to mostly groundwater recharge, it is not expected that the loads will have changed significantly between 1991 and 1998. Point source loads for the summer low flow critical conditions made up the balance of the total allowable load. It was assumed that the Fairlee WWTP was not discharging to the Creek. Details of this modeling activity are described further in the technical memorandum entitled *Significant Nutrient Point Sources in the Fairlee Creek Watershed*.

The fourth scenario represented future conditions, without the Fairlee WWTP, for the case of average stream flow. The total nonpoint source flows were the same as for scenario 2. The nonpoint source loads reflect estimated year 2000 loads for both nitrogen and phosphorus. The total year 2000 nonpoint source loads were calculated using the same methodology described in the beginning of the document, for the 1991 loads. The year 2000 loading rates were based on the results of the Chesapeake Bay Model (U.S. EPA, 1991), and accounted for loads from both atmospheric deposition and septic tanks. It was estimated, from Maryland Department of Agriculture's Agricultural BMP database and reduction factors from the Tributary Strategies Technical Appendix, that a 14.6% reduction in nitrogen loads, and a 9.1% reduction in phosphorus loads have already been implemented in the Fairlee Creek Basin. The reductions are low because the only agricultural BMPs are those from farms which participate in the State's Cost share program.

Table A9 shows the applicable acres of four agricultural BMP types located in the Fairlee Creek Basin.[3] Table A9 shows the reduction factors used to calculate the reductions, and the nitrogen and phosphorus load reductions. The reduction factors for the nutrient management plans and the soil conservation and water quality plans were taken directly from the Tributary Strategies Technical Appendix. The reduction factors for conservation tillage were calculated as the difference between the high-tillage loading factor and the low-tillage loading factor for both nitrogen and phosphorus. The cover crop reduction factors for both nutrients were calculated as a percent reduction in loading multiplied by the loading factor for both high-tillage land and low-tillage land. The nonpoint source loads used in all the model scenario runs can be seen in Table A10.

Point source loads for the average annual conditions made up the balance of the total allowable load. It was assumed that the Fairlee WWTP was not discharging to the Creek. Details of this modeling activity are described further in the technical memorandum entitled *Significant Nutrient Point Sources in the Fairlee Creek Watershed.*

Scenario Results

Base Case Scenarios:

1. *Low Flow:* Assumes low stream flow conditions. Assumes the 1991 low flow nonpoint source loads, and 1991 average July and August point source loads for the point sources.

2. *Average Annual Flow:* Assumes average stream flow conditions. Assumes the 1991 average annual nonpoint source loads, and 1991 average annual point source loads for the point sources.

The first scenario represents the base case for summer low flow conditions when water quality is impaired by high chlorophyll *a* levels, and low dissolved oxygen concentrations. The results for scenarios 3 and 4 can be seen in Figures A24-A31. In both scenarios, the peak chlorophyll *a* levels are above the desired goal of 50 µg/l (Figure A25). Figure A25 shows the dissolved oxygen levels for these scenarios. It can be seen that the dissolved oxygen level falls below the standard of 5 mg/l in scenario one.

It would appear that as the flow increases the chlorophyll *a* problem worsens, except between river kilometers 4.86 and 5.5. However, the model results reflect extreme conditions. The second model scenario was run at steady state conditions for 35 days with summer temperatures

3 No reductions were assumed for BMPs for which reductions were difficult to measure ie. spring development, roof runoff management, and ponds. It was also assumed that 20% of the BMPs were captured in the calibration of the original loading rates.

(above 70 ^{o}F). It is unlikely that average flow conditions would occur for that length of time during summer conditions. It is therefore unlikely that the Creek would receive the heavy loadings in the summer that were assumed in this model scenario.

Future Condition Scenarios:

3. *Low Flow:* Assumes low stream flow conditions. Assumes 1991 summer low flow nonpoint source loads plus a 3% margin of safety. Assumes point source loads for the summer low flow critical conditions make up the balance of the total allowable load.

4. *Average Annual Flow:* Assumes average stream flow conditions. Assume year 2000 nonpoint source loads reduced by 10%, plus a 3% margin of safety added to the computed loads. Assumes that point source loads for the average annual conditions make up the balance of the total allowable load.

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

Diurnal Dissolved Oxygen Calculations

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

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

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

Where:

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

(Thomman and Mueller, 1987)

For both model scenarios 3 and 4, where there is the greatest potential for a diurnal dissolved oxygen problem, the variation due to photosynthesis and respiration was calculated and subtracted from the average dissolved oxygen values produced by the model. The results from scenarios 3 and 4 can be seen in Figures A32-A39.

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 along the mainstem of the Fairlee Creek. The fourth scenario shows that water quality standards for both chlorophyll *a* and dissolved oxygen are achieved along the entire length of the Creek during average flow conditions. The results from scenarios 3 and 4 also showed that water quality is protected for the full length of the Fairlee Creek and the three tributaries that were modeled.

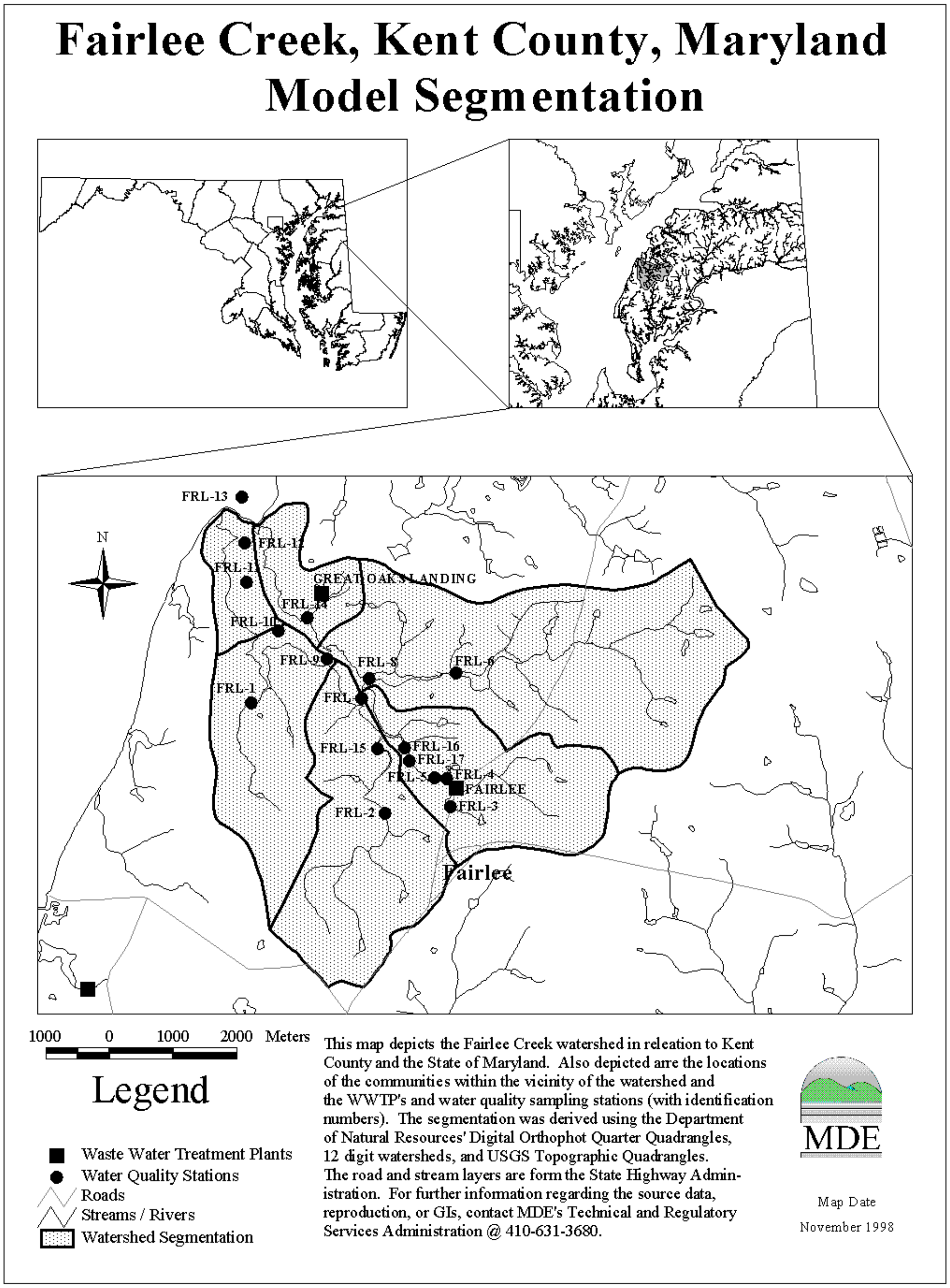

Figure A1: Fairlee Creek Location and Water Quality Map

Table A1: Field and Laboratory Protocols

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

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

Table A2: Location of Water Quality Monitoring Stations Along Main Branch and Southeast Tributary

Water Quality Station	Kilometers from Mouth of Fairlee Creek
FRL-13	0.160
FRL-12	1.010
FRL-11	1.600
FRL-10	2.520
FRL-9	3.390
FRL-7	4.220
FRL-16	5.370
FRL-17	5.630
FRL-5	6.310
FRL-4	6.600

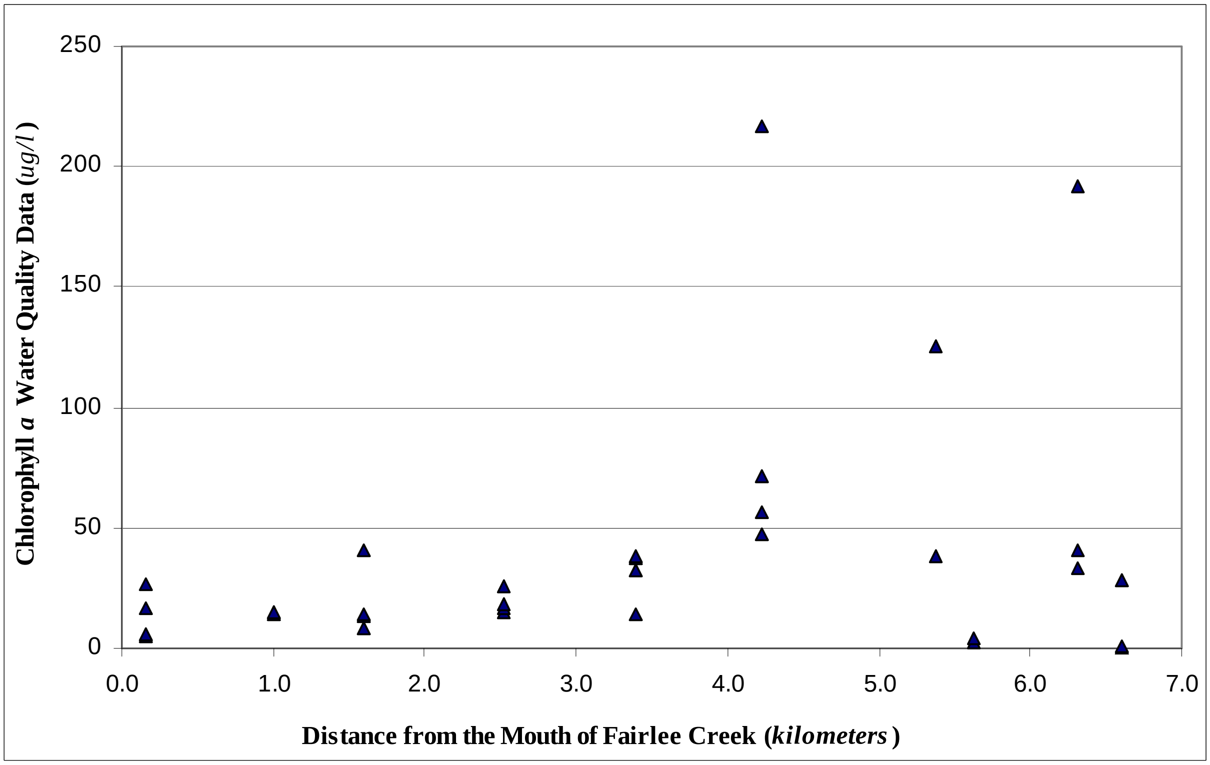

Figure A2: Longitudinal Profile of Chlorophyll *a* Data

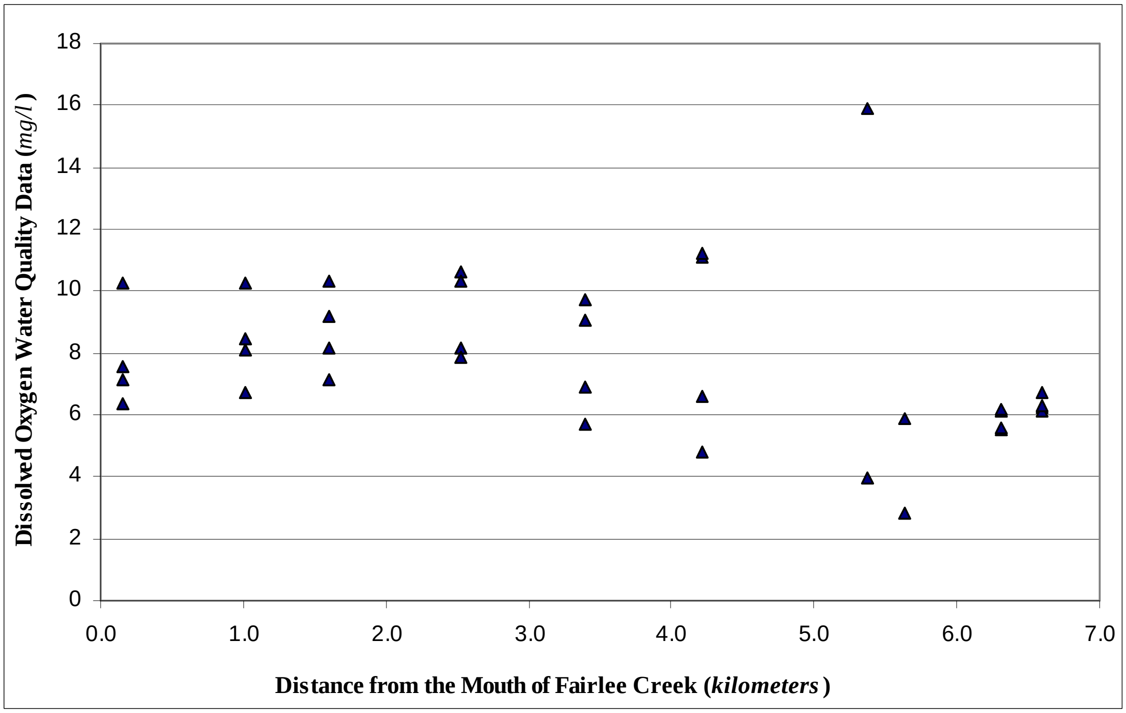

Figure A3: Longitudinal Profile of Dissolved Oxygen Data

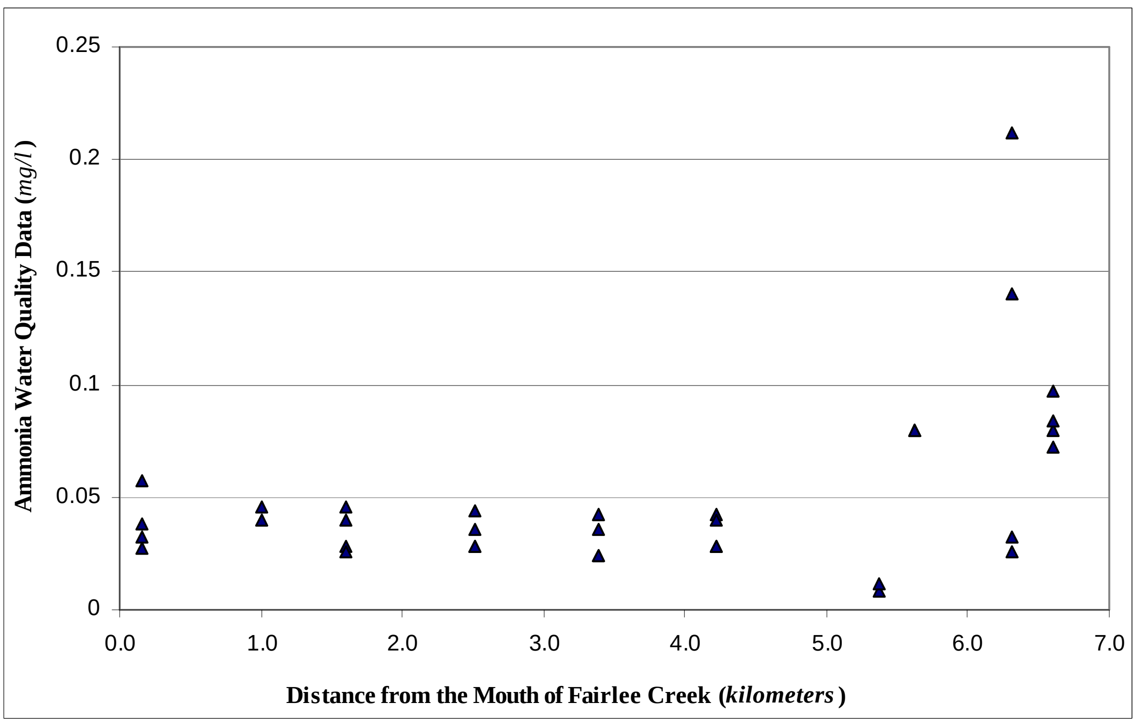

Figure A4: Longitudinal Profile of Ammonia Data

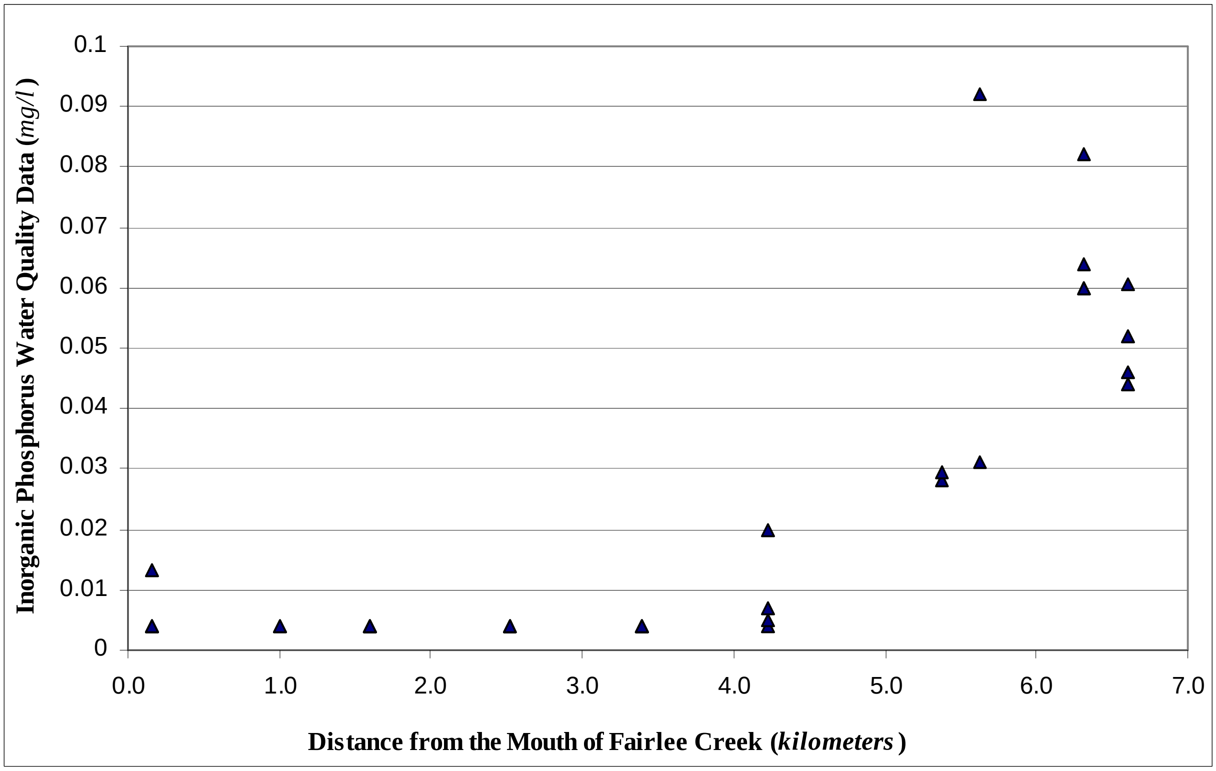

Figure A5: Longitudinal Profile of Inorganic Phosphorus Data

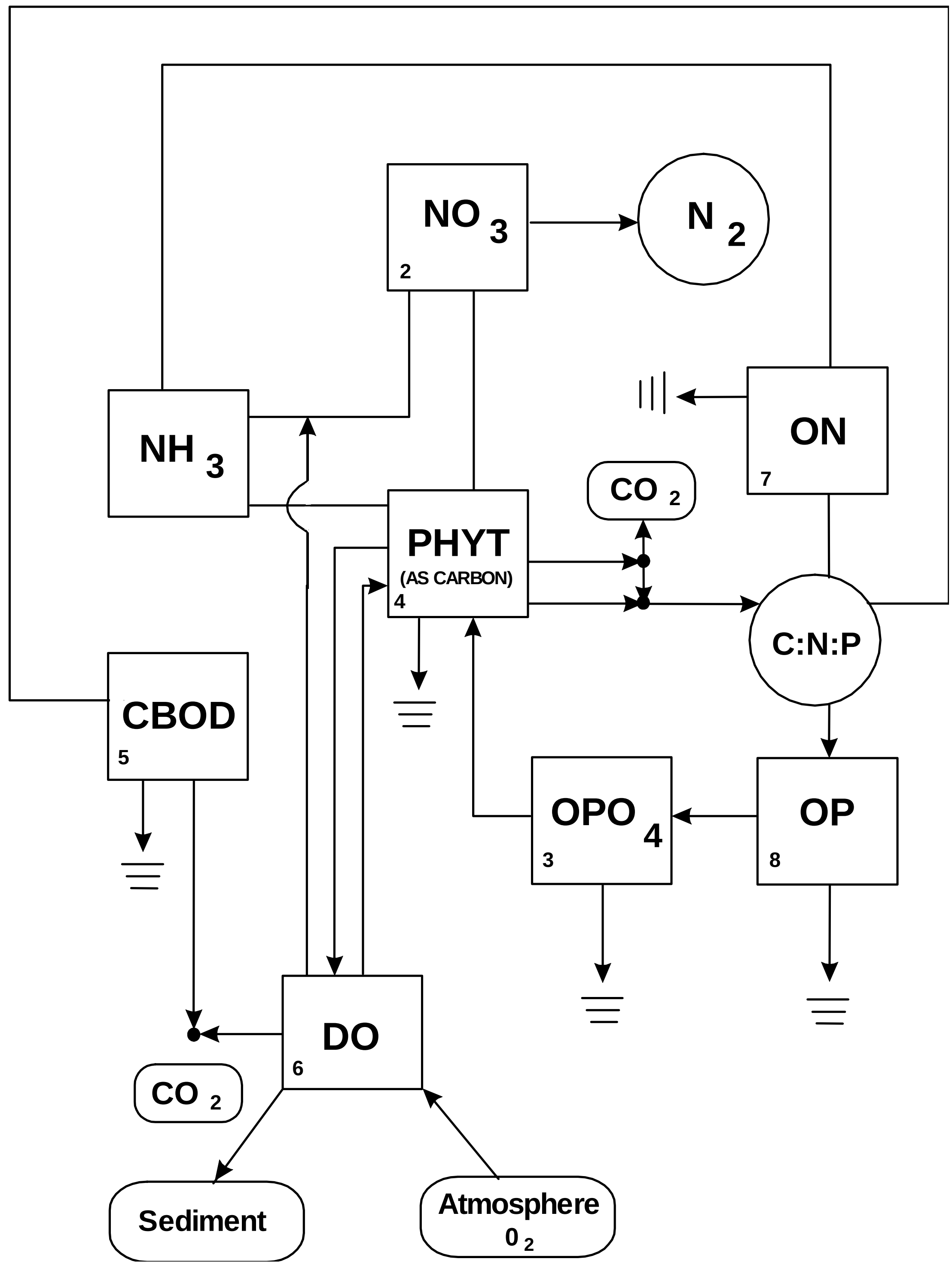

Figure A6: State Variables and Kinetic Interactions in EUTRO5

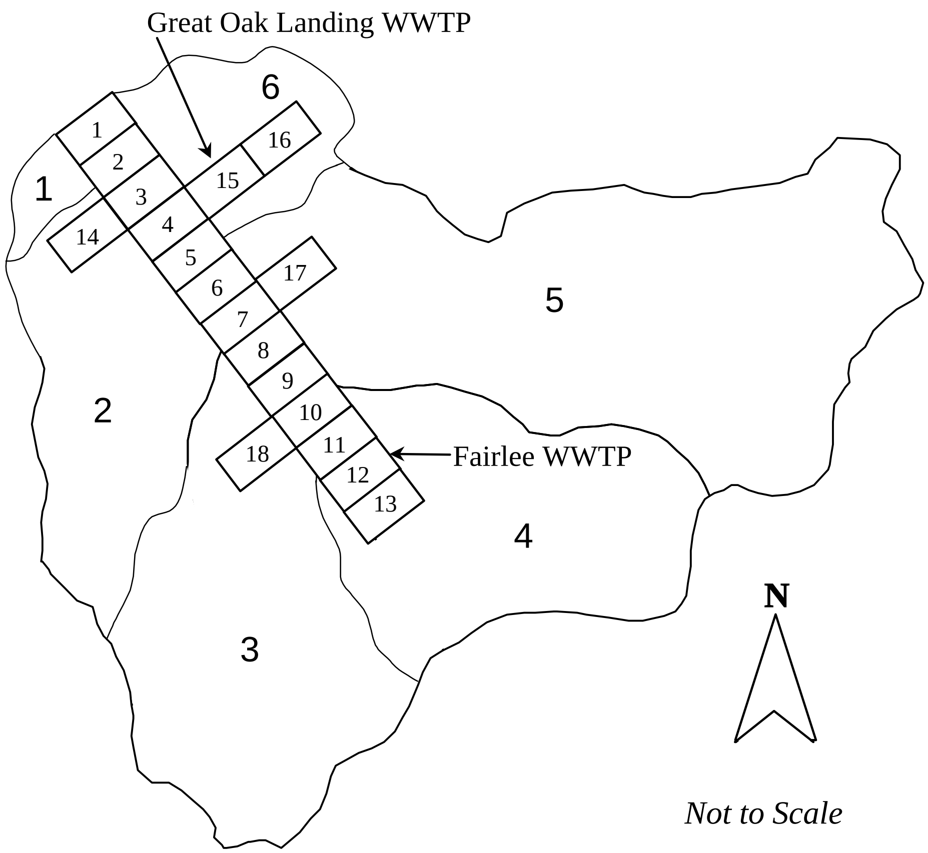

Figure A7: Model Segmentation, including Subwatersheds and Location of WWTPs

Table A3: Volumes, Characteristic Lengths, and Interfacial Areas used in the FCEM

Segment No.	Volume m^3	Characteristic Length m	Interfacial Area m^2
1	304,584	493.0	800
2	639,158	739.5	806
3	247,233	579.5	676
4	78,356	259.0	516
5	211,557	350.5	385
6	128,271	518.5	264
7	41,422	335.5	226
8	40,589	213.5	166
9	35,757	394.0	66
10	876	272.0	1.46
11	812	428.0	1.46
12	717	523.0	1.46
13	66	268.0	1.46
14	94,401	694.5	99.9
15	25,529	387.5	56.0
16	47	278.0	0.47
17	47,832	780.0	36.5
18	1,287	442.0	1.46

Table A4: Contributing Watersheds to each Model Segment

Segment Number	Contributing Subwatershed
13	4
14	1 & 2
16	6
17	5
18	3

Table A5: Point Source Loadings for the Calibration of the Model

		Fairlee	Great Oak Landing
Flow	*m3/s*	0.00263	0.000219
NH4	*kg/d*	0.0496	0.0360
NO23	*kg/d*	0.00569	0.000948
PO4	*kg/d*	0.0199	0.0322
CHL *a*	*kg/d*	1.34	0.018
CBOD	*kg/d*	4.56	0.463
DO	*kg/d*	1.31	0.106
ON	*kg/d*	1.78	0.142
OP	*kg/d*	0.163	0.0284

Table A6: Nonpoint Source Loadings for the Calibration of the Model

Segment	Flow	NH4	NO23	PO4	CHL *a*	CBOD	DO	ON	OP
	m3/s	*mg/l*	*mg/l*	*mg/l*	*ug/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*
1	0.0000	0.0397	0.208	0.00655	13.5	2.62	7.55	0.627	0.0663
13	0.0215	0.0869	1.37	0.0537	9.60	2.62	6.31	0.570	0.198
14	0.0197	0.0387	0.0200	0.00633	29.1	2.62	7.48	1.33	0.255
16	0.0067	0.0387	0.0200	0.00633	29.1	2.62	7.48	1.33	0.255
17	0.0531	0.0933	0.0433	0.00433	34.9	2.62	5.30	1.47	0.160
18	0.0279	0.0660	3.12	0.0387	0.823	0.729	6.70	0.455	0.0507

Table A7: Environmental Parameters for the Calibration of the Model

Calibration Evironmental Parameters

Segment	K_e	T	Salinity	SOD	FNH_4	FPO_4
	m^{-1}	^oC	g/L	$g\ O_2/m^2\ day$	$mg\ NH_4\_N/m^2\ day$	$mg\ PO_4\_P/m^2\ day$
1	1.95	26.8	7.20	0.40	0	0
2	2.29	26.9	7.15	0.40	0	0
3	4.11	27.9	6.88	0.40	0	0
4	5.27	27.8	6.62	0.40	0	0
5	5.27	27.8	6.62	0.40	0	0
6	5.27	27.8	6.62	0.40	0	0
7	9.75	28.3	5.65	0.40	0	0
8	9.75	28.3	5.65	0.40	0	0
9	9.75	28.3	5.65	0.40	0	0
10	9.00	26.2	1.28	1.00	260	36
11	3.90	23.2	0.00	4.00	260	36
12	3.90	21.9	0.00	4.00	260	36
13	3.90	21.1	0.00	4.00	260	36
14	11.1	27.7	6.78	0.40	30	10
15	6.50	28.0	6.60	0.40	30	10
16	6.50	28.0	6.60	0.40	30	10
17	9.75	28.5	5.95	0.40	30	10
18	9.75	27.3	2.43	4.00	260	36

Table A8: EUTRO5 Kinetic Coefficients

Constant	Code	Value
Nitrification rate	K12C	0.12 *day* -1 at 20^o C
temperature coefficient	K12T	1.08
Denitrification rate	K20C	0.09 *day* -1 at 20^o C
temperature coefficient	K20T	1.045
Saturated growth rate of phytoplankton	K1C	2.0 *day* -1 at 20^o C
temperature coefficient	K1T	1.068
Endogenous respiration rate	K1RC	0.25 *day* -1 at 20^o C
temperature coefficient	K1RT	1.045
Nonpredatory phytoplankton death rate	K1D	0.02 *day* -1
Phytophankton Stoichometry		
Oxygen-to-carbon ratio	ORCB	2.67 $mg\ O_2 / mg\ C$
Carbon-to-chlorophyll ratio	CCHL	30
Nitrogen-to-carbon ratio	NCRB	0.25 *mg N/mg C*
Phosphorus-to-carbon ratio	PCRB	0.025 $mg\ PO_4$*-P/ mg C*
Half-saturation constants for phytoplankton growth		
Nitrogen	KMNG1	0.025 *mg* N / L
Phosphorus	KMPG1	0.001 *mg* P / P
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	0.5
phosphorus	FOP	0.5
Light Formulation Switch	LGHTS	1 = Smith
Saturation light intensity for phytoplankton	IS1	200. *Ly/day*
BOD deoxygenation rate	KDC	0.30 *day* -1 at 20^o C
temperature coefficient	KDT	1.047
Half saturation const. for carb. deoxygenation	KBOD	0.5
Reaeration rate constant	k2	0.20 *day* -1 at 20^o C
Mineralization rate of dissolved organic nitrogen	K71C	0.075 *day* -1
temperature coefficient	K71T	1.08
Mineralization rate of dissolved organic phosphorus	K58C	0.22 *day* -1
temperature coefficient	K58T	1.08
Phytoplankton settling velocity		0.0432 *m/day*
Inorganics settling velocity		3.45 *m/day*

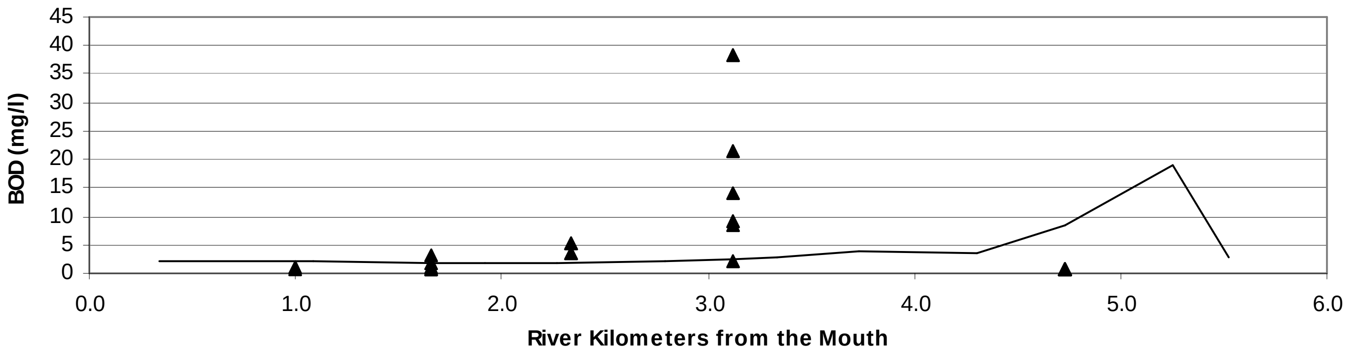

Figure A8: BOD vs. River Kilometers for the Calibration of the Model

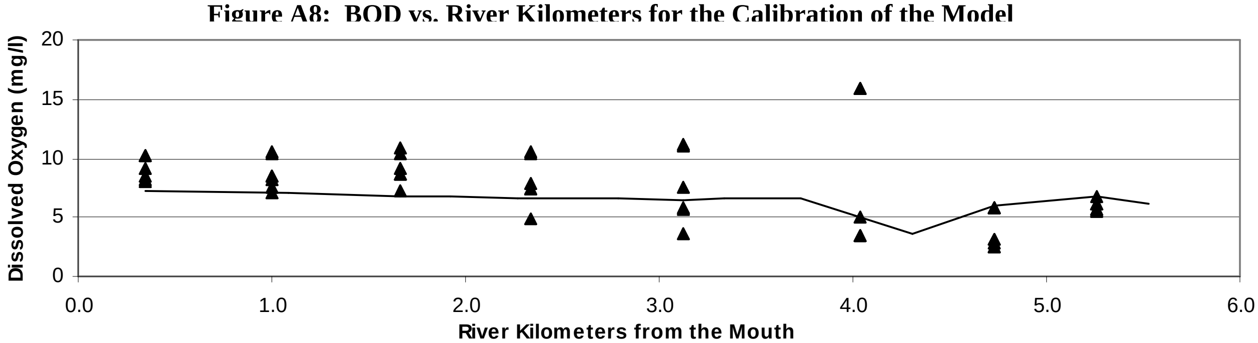

Figure A9: Dissolved Oxygen vs. River Kilometers for the Calibration of the Model

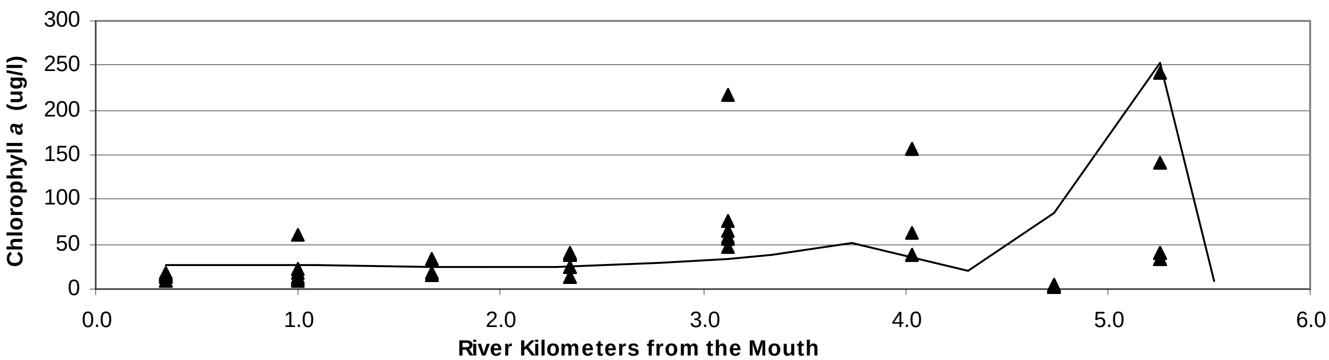

Figure A10: Chlorophyll *a* vs. River Kilometers for the Calibration of the Model

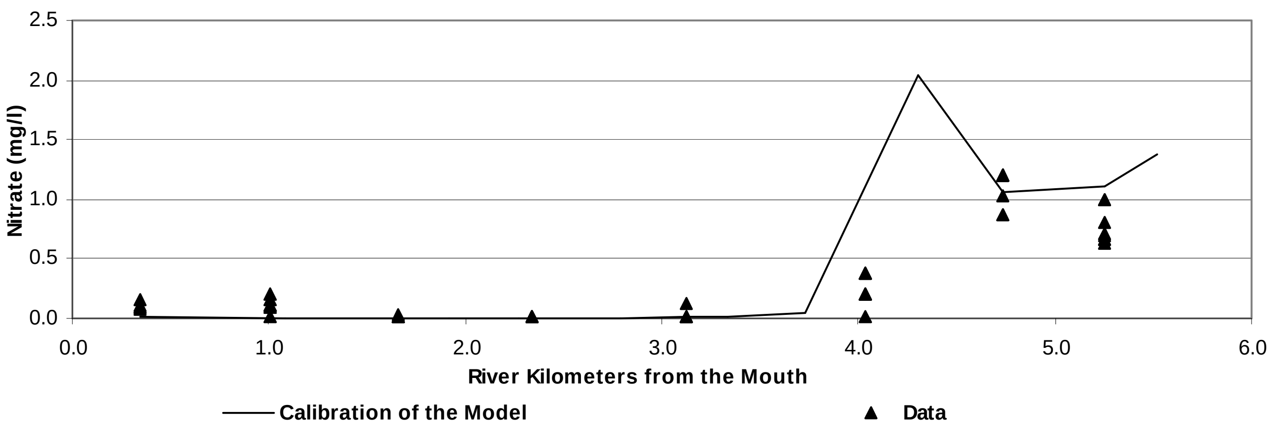

Figure A11: Nitrate (plus Nitrite) vs. River Kilometers for the Calibration of the Model

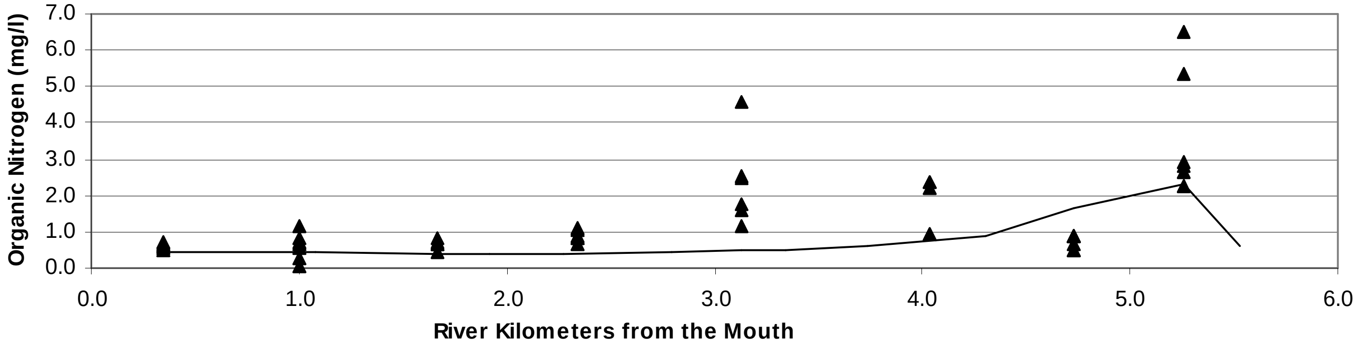

Figure A12: Organic Nitrogen vs. River Kilometers for the Calibration of the Model

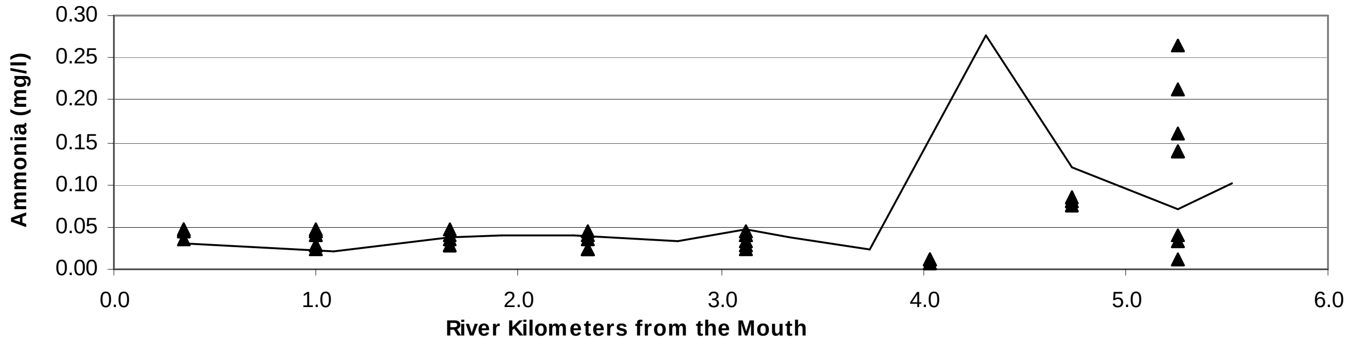

Figure A13: Ammonia vs. River Kilometers for the Calibration of the Model

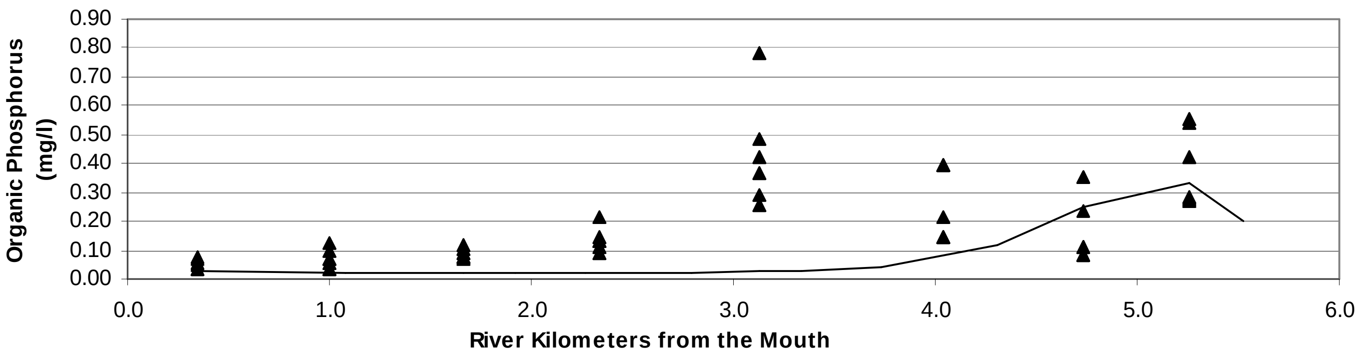

Figure A14: Organic Phosphorus vs. River Kilometers for the Calibration of the Model

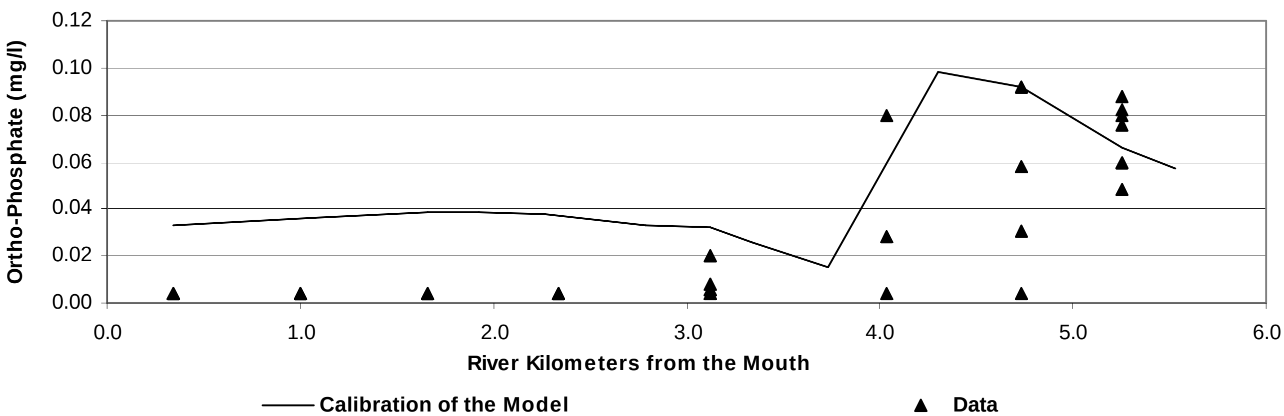

Figure A15: Ortho-Phosphate vs. River Kilometers for the Calibration of the Model

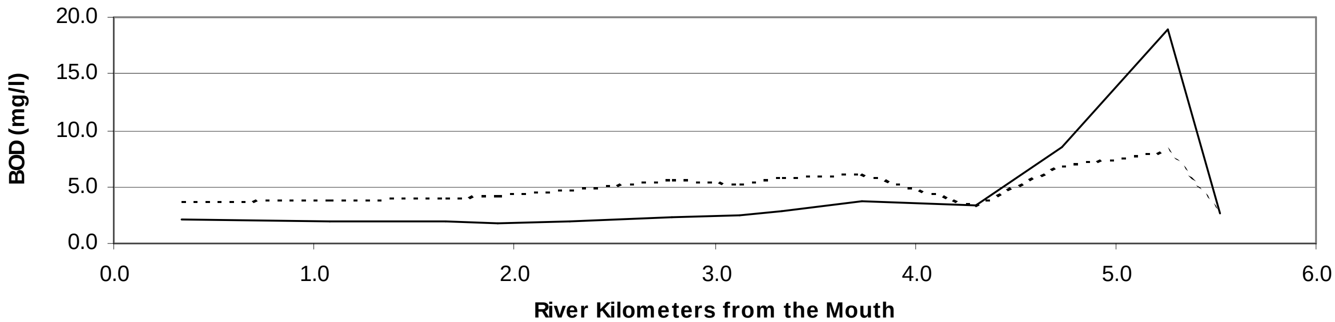

Figure A16: BOD vs. River Kilometers for the Sensitivity Analysis

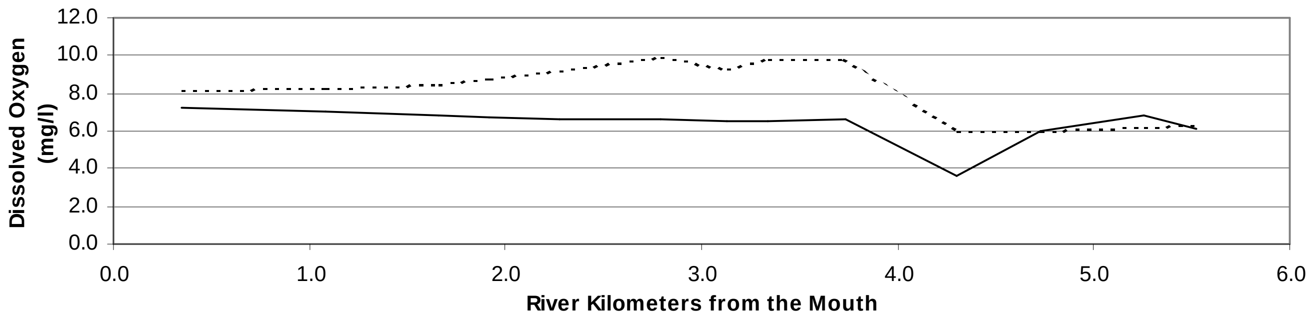

Figure A17: Dissolved Oxygen vs. River Kilometers for the Sensitivity Analysis

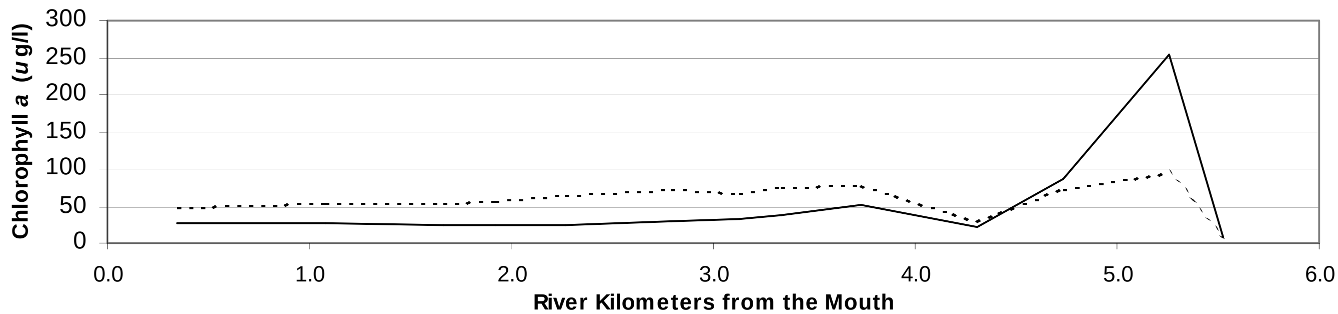

Figure A18: Chlorophyll *a* vs. River Kilometers for the Sensitivity Analysis

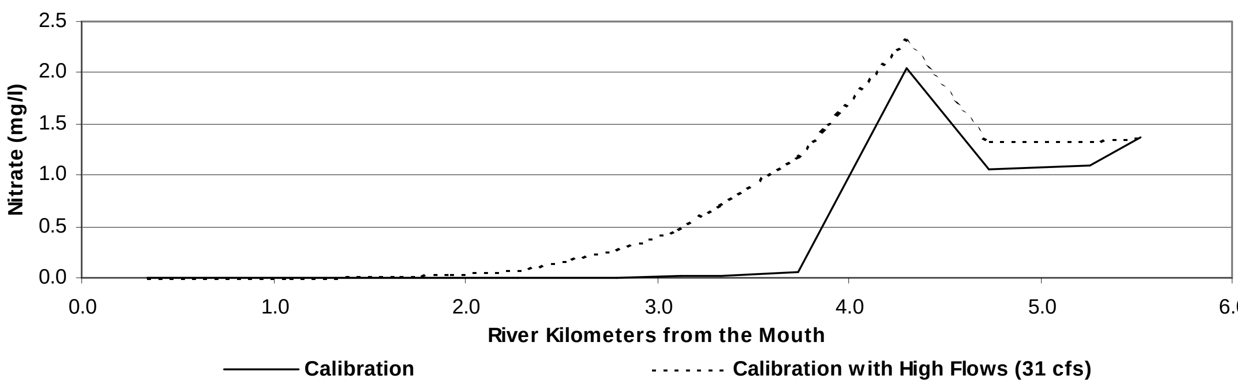

Figure A19: Nitrate (plus Nitrite) vs. River Kilometers for the Sensitivity Analysis

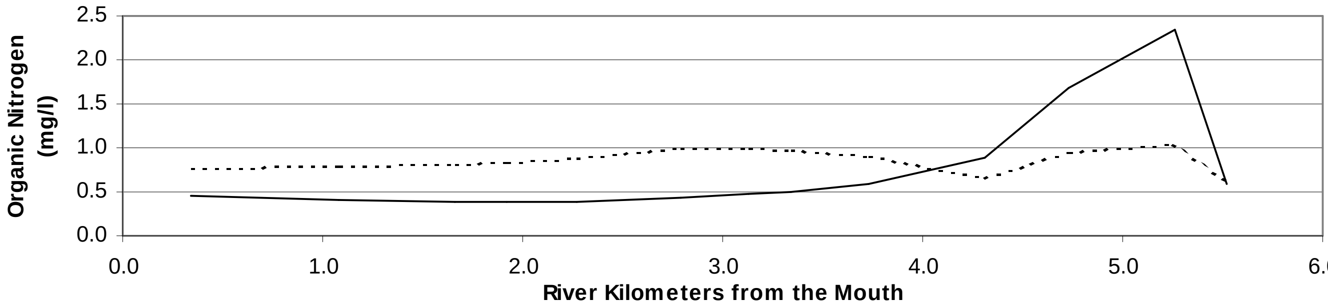

Figure A20: Organic Nitrogen vs. River Kilometers for the Sensitivity Analysis

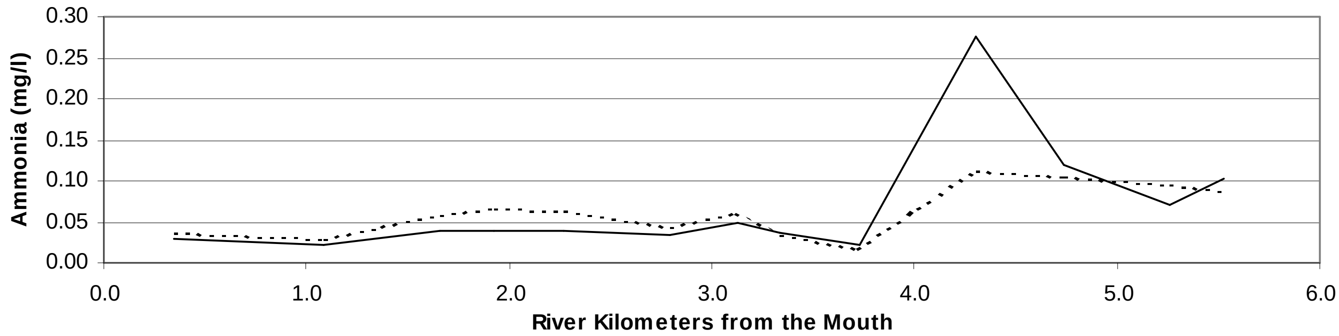

Figure A21: Ammonia vs. River Kilometers for the Sensitivity Analysis

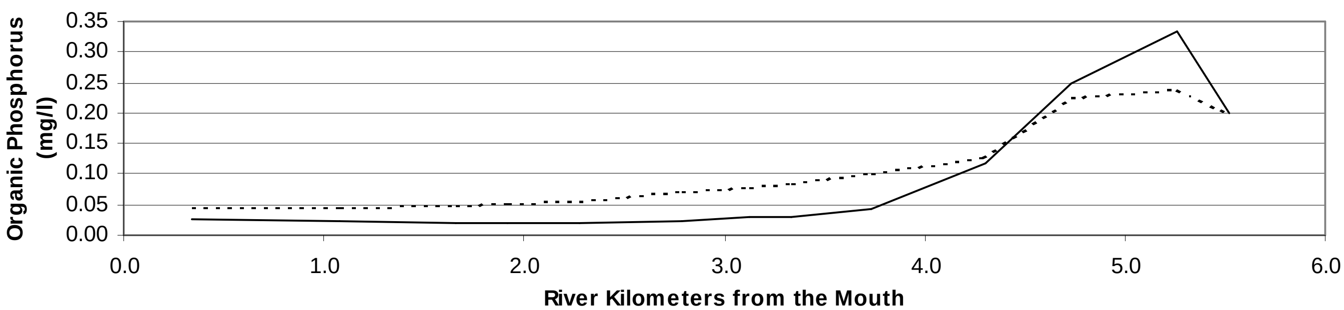

Figure A22: Organic Phosphorus vs. River Kilometers for the Sensitivity Analysis

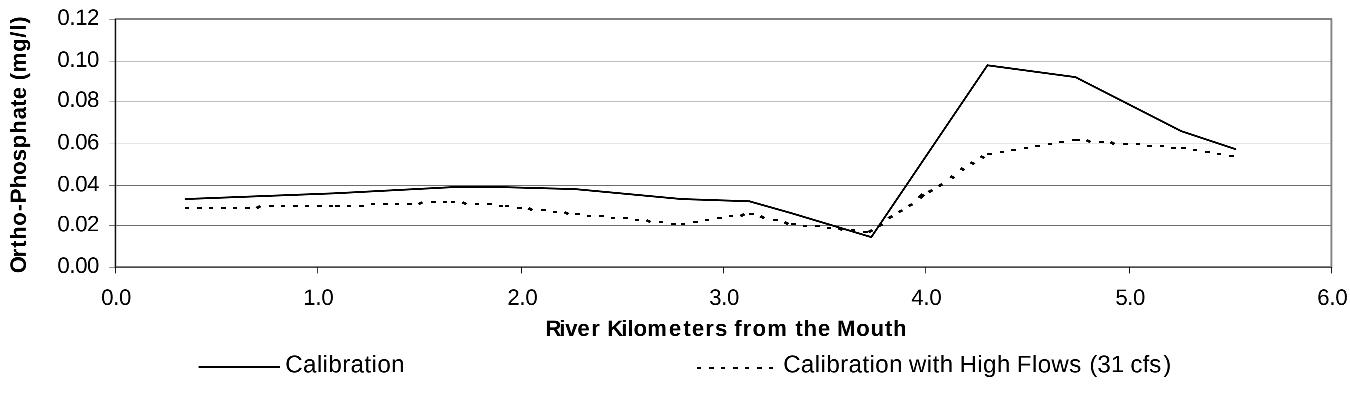

Figure A23: Ortho-Phosphate vs. River Kilometers for the Sensitivity Analysis

Table A9: Load reduction implemented through existing Agricultural BMPs

Best Management Practice Type	Applicable Acres *acres*	Nitrogen Reduction Factor *lb/ac/yr*	Phosphorus Reduction Factor *lb/ac/yr*	Nitrogen Reduction *lb/yr*	Phosphorus Reduction *lb/yr*
Conservation Tillage	727.92	6.79	0.47	4939.5	343.9
Cover Crops	1049.28	5.71	0.00	5992.3	0.0
Nutrient Management Plans	189.48	3.10	0.10	587.4	18.9
Soil Conservation & Water Quality Plans	1069.46	1.3	0.2	1390.3	213.9

Table A10: Nonpoint Source Concentrations for the Model Scenarios

Scenario		1	2	3	4
Segment 1					
CBOD	*mg/l*	2.62	2.62	2.62	2.62
Dissolved Oxygen	*mg/l*	7.55	7.55	7.55	7.55
Total Nitrogen	*mg/l*	0.875	0.875	0.875	0.814
Total Phosphorus	*mg/l*	0.0728	0.0728	0.0728	0.0684
Flow	m^3/s	0.0000	0.0000	0.0000	0.0000
Segment 13					
CBOD	*mg/l*	2.62	2.62	2.62	2.62
Dissolved Oxygen	*mg/l*	6.31	6.31	6.31	6.31
Total Nitrogen	*mg/l*	2.03	4.14	2.03	3.85
Total Phosphorus	*mg/l*	0.252	0.298	0.252	0.281
Flow	m^3/s	0.0215	0.05487	0.0215	0.05487
Segment 14					
CBOD	*mg/l*	2.62	2.62	2.62	2.62
Dissolved Oxygen	*mg/l*	7.48	7.48	7.48	7.48
Total Nitrogen	*mg/l*	1.39	3.73	1.39	3.47
Total Phosphorus	*mg/l*	0.261	0.262	0.261	0.246
Flow	m^3/s	0.0197	0.05323	0.0197	0.05323
Segment 16					
CBOD	*mg/l*	2.62	2.62	2.62	2.62
Dissolved Oxygen	*mg/l*	7.48	7.48	7.48	7.48
Total Nitrogen	*mg/l*	1.39	3.51	1.39	3.27
Total Phosphorus	*mg/l*	0.261	0.25096	0.261	0.236
Flow	m^3/s	0.0067	0.01644	0.0067	0.01644
Segment 17					
CBOD	*mg/l*	2.62	2.62	2.62	2.62
Dissolved Oxygen	*mg/l*	5.30	5.30	5.30	5.30
Total Nitrogen	*mg/l*	1.60	4.34	1.60	4.04
Total Phosphorus	*mg/l*	0.164	0.315	0.164	0.297
Flow	m^3/s	0.0531	0.12005	0.0531	0.120
Segment 18					
CBOD	*mg/l*	0.729	0.729	0.729	0.729
Dissolved Oxygen	*mg/l*	6.70	6.70	6.70	6.70
Total Nitrogen	*mg/l*	3.64	3.9	3.64	3.64
Total Phosphorus	*mg/l*	0.0893	0.279	0.0893	0.263
Flow	m^3/s	0.0279	0.06793	0.0279	0.06793

Table A11: Point Source Loadings for the Model Scenarios 1 and 2

Scenario		1	2
Fairlee WWTP			
CBOD	*kg/d*	4.56	4.56
Dissolved Oxygen	*kg/d*	1.31	1.31
Total Nitrogen	*kg/d*	1.84	1.84
Total Phosphorus	*kg/d*	0.183	0.183
Flow	m^3/s	0.00263	0.00263
Great Oak Landing WWTP			
CBOD	*kg/d*	0.463	0.463
Dissolved Oxygen	*kg/d*	0.106	0.106
Total Nitrogen	*kg/d*	0.179	0.179
Total Phosphorus	*kg/d*	0.0607	0.0607
Flow	m^3/s	0.00022	0.00022

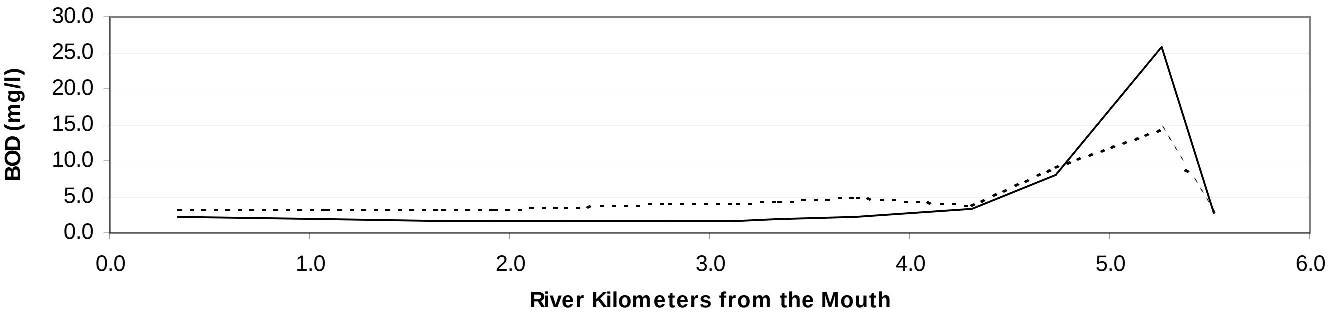

Figure A24: BOD vs. River Kilometers for the Base Case Scenarios

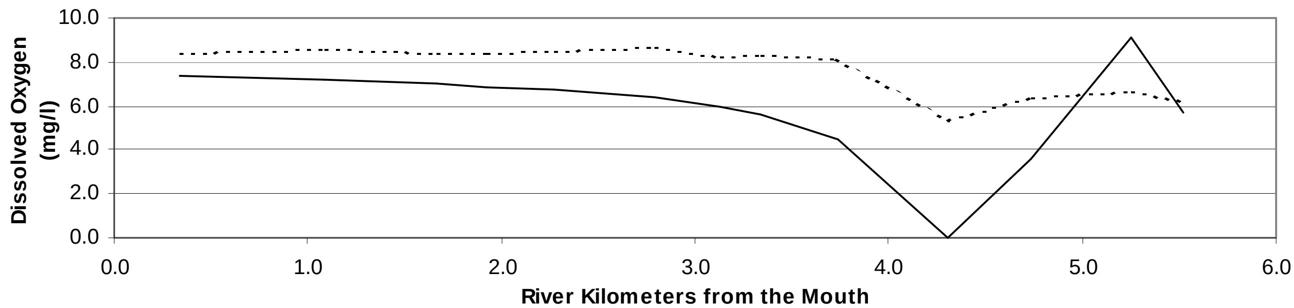

Figure A25: Dissolved Oxygen vs. River Kilometers for the Base Case Scenarios

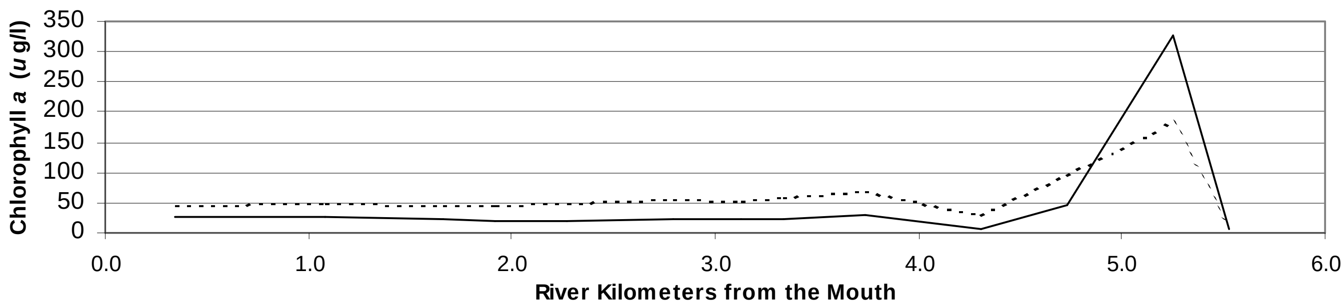

Figure A26: Chlorophyll *a* vs. River Kilometers for the Base Case Scenarios

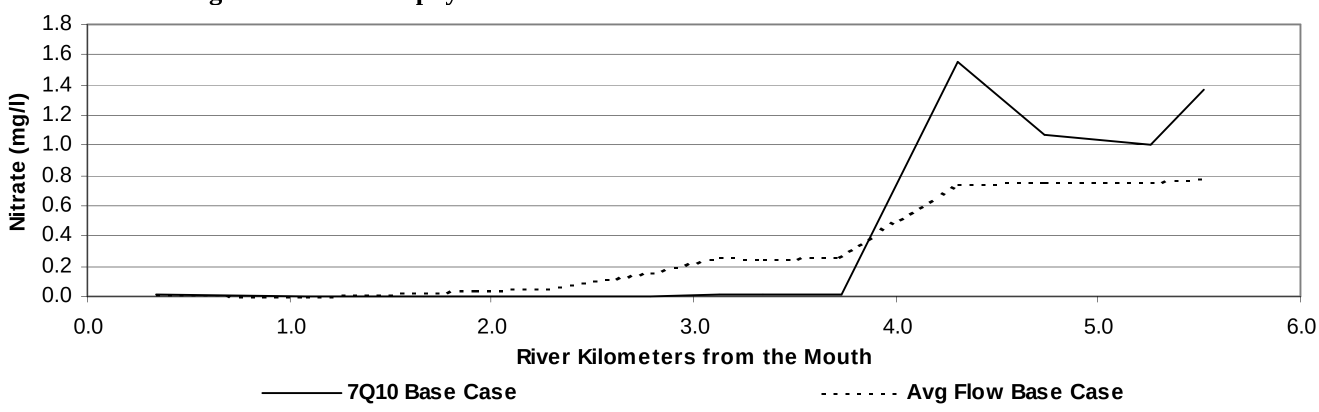

Figure A27: Nitrate vs. River Kilometers for the Base Case Scenarios

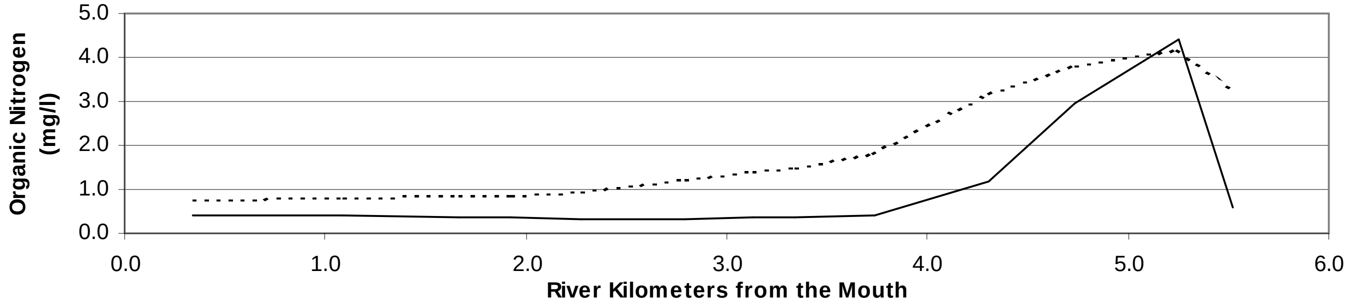

Figure A28: Organic Nitrogen vs. River Kilometers for the Base Case Scenarios

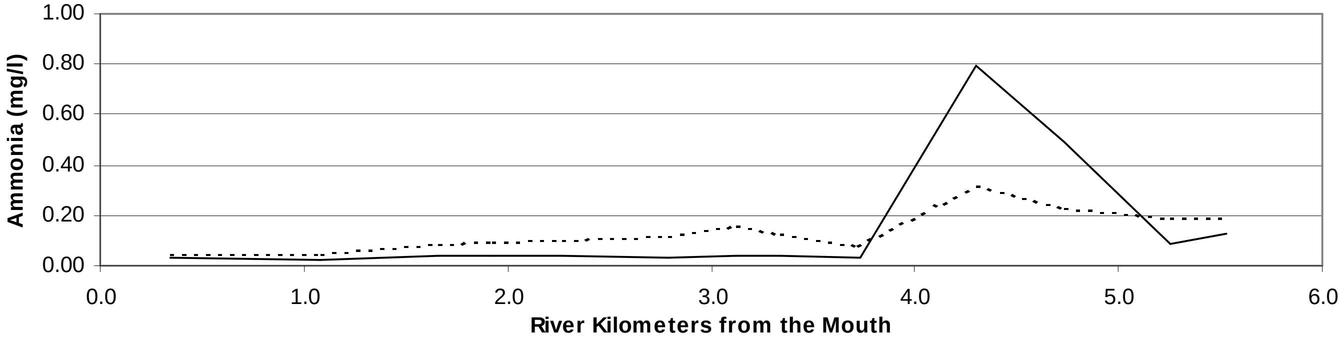

Figure A29: Ammonia vs. River Kilometers for the Base Case Scenarios

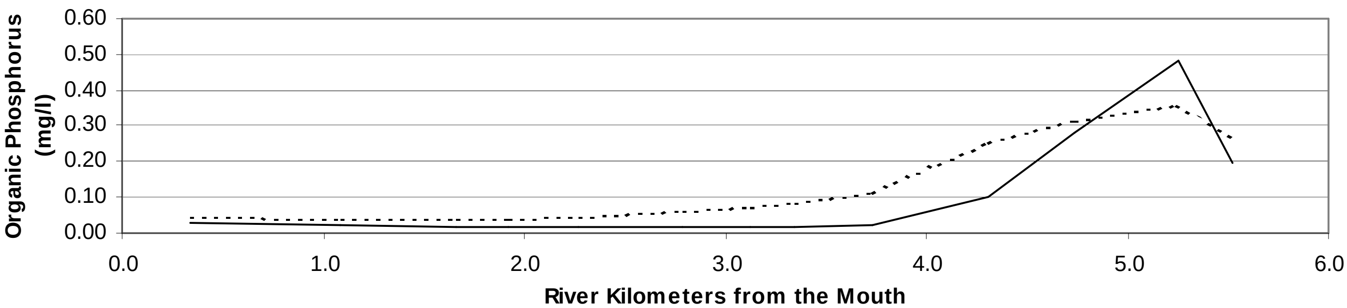

Figure A30: Organic Phosphorus vs. River Kilometers for the Base Case Scenarios

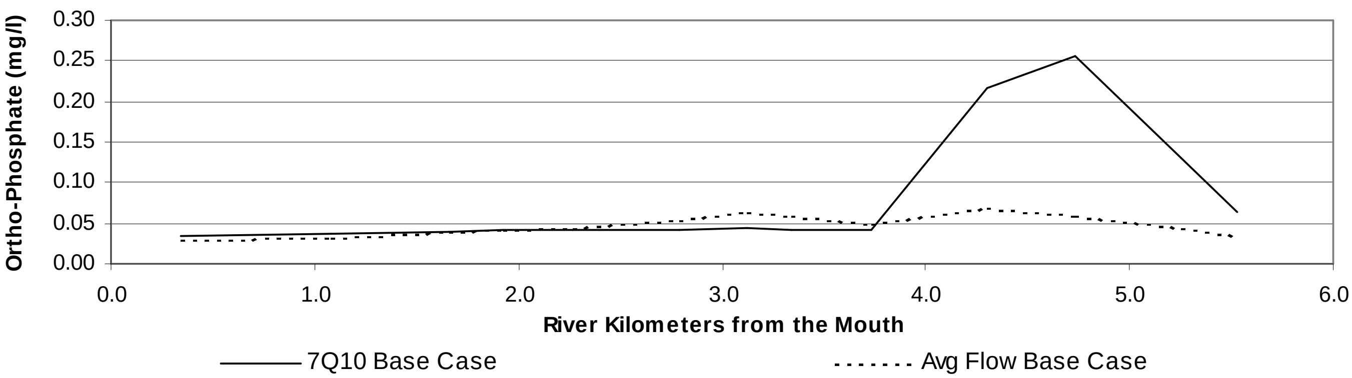

Figure A31: Ortho-Phosphate vs. River Kilometers for the Base Case Scenarios

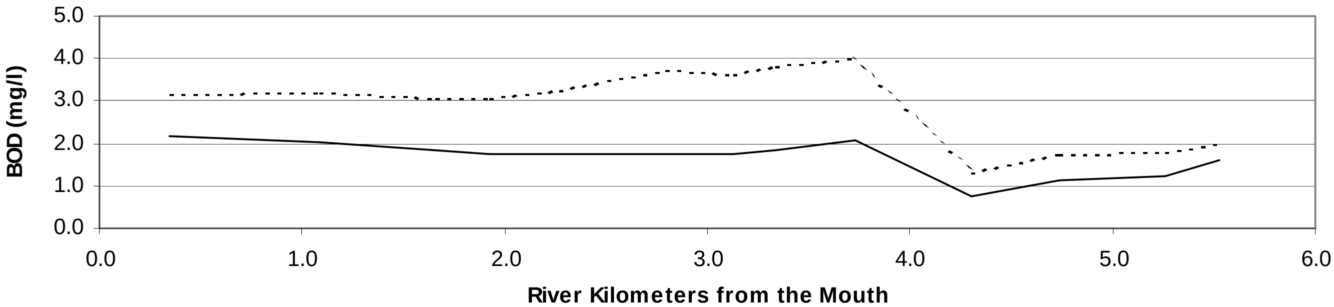

Figure A32: BOD vs. River Kilometers for the Future Case Scenarios

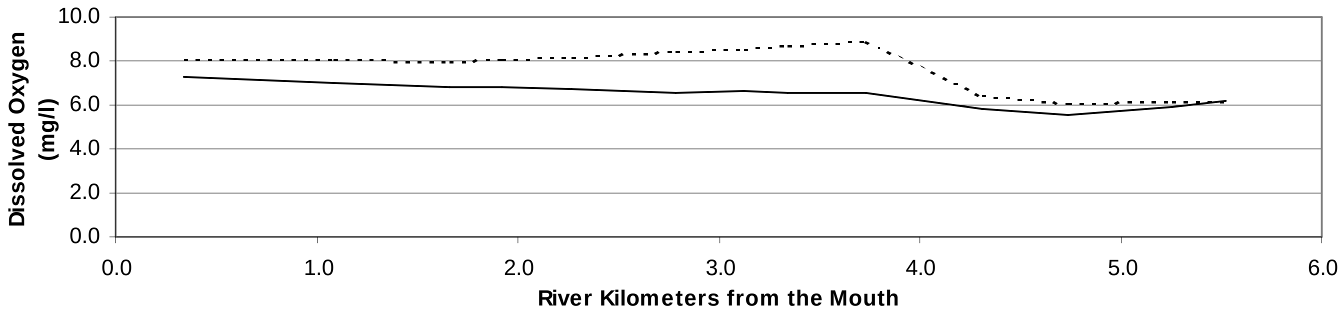

Figure A33: Dissolved Oxygen vs. River Kilometers for the Future Case Scenarios

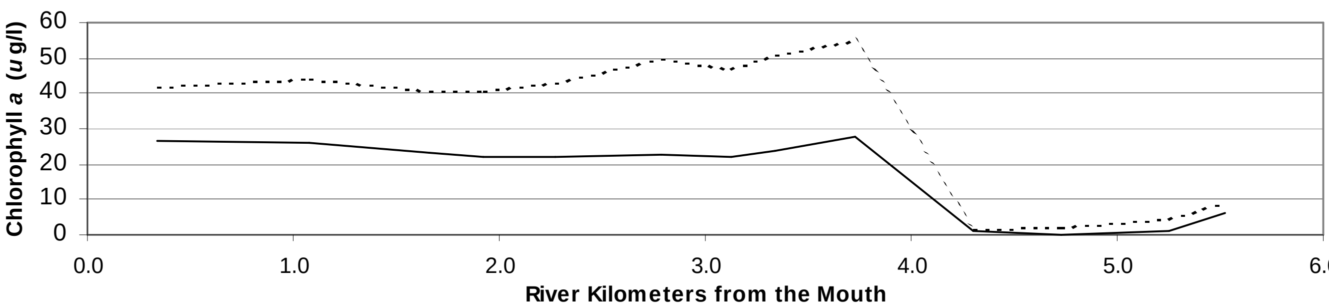

Figure A34: Chlorophyll *a* vs. River Kilometers for the Future Case Scenarios

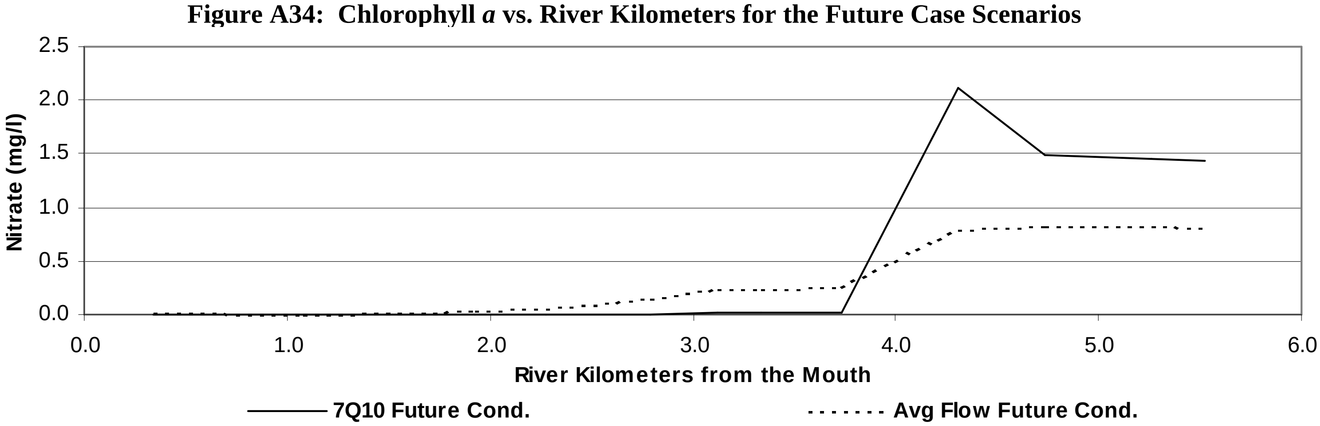

Figure A35: Nitrate (plus Nitrite) vs. River Kilometers for the Future Case Scenarios

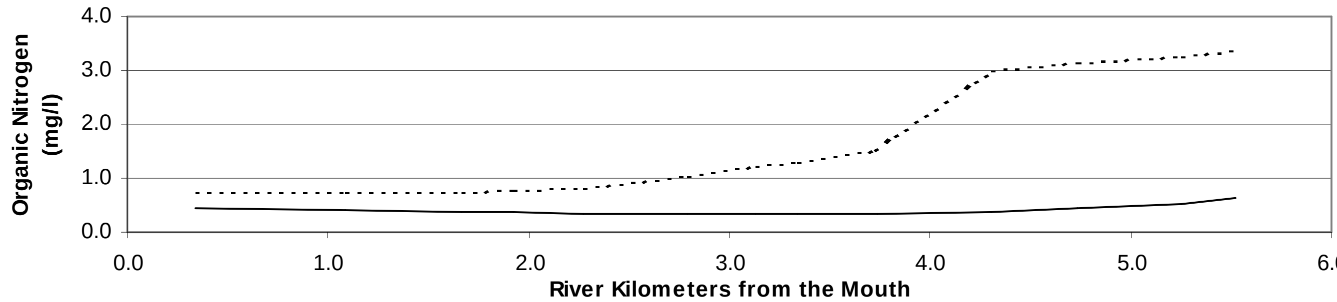

Figure A36: Organic Nitrogen vs. River Kilometers for the Future Case Scenarios

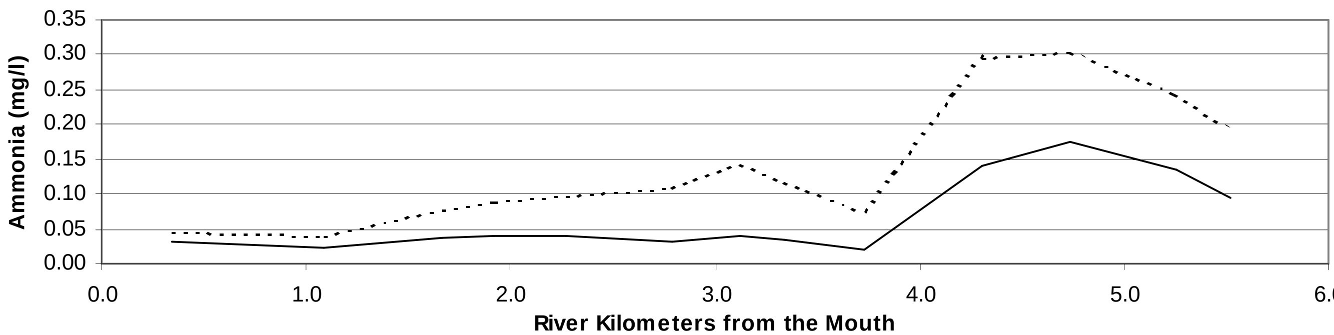

Figure A37: Ammonia vs. River Kilometers for the Future Case Scenarios

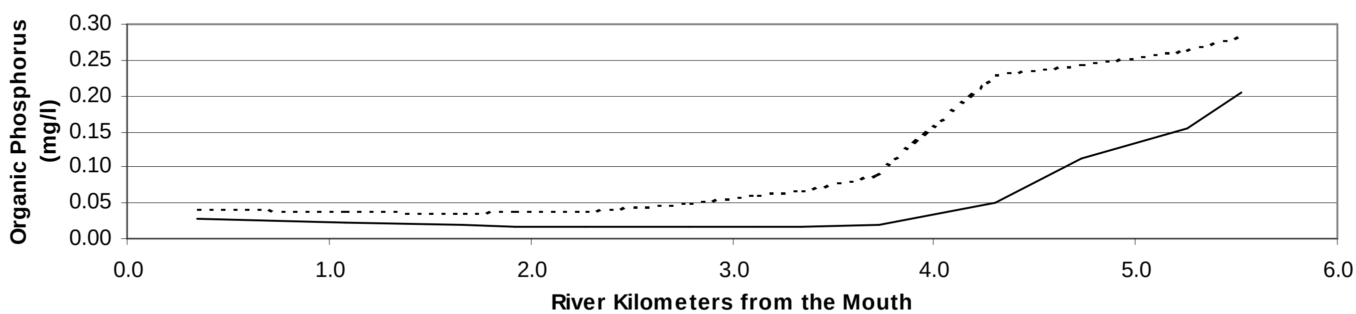

Figure A38: Organic Phosphorus vs. River Kilometers for the Future Case Scenarios

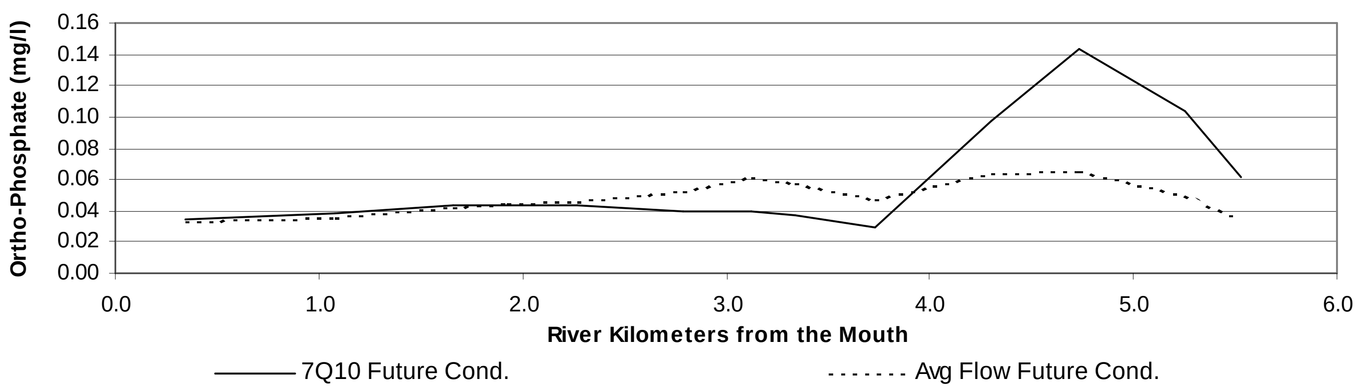

Figure A39: Ortho-Phosphate vs. River Kilometers for the Future Case Scenarios

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