Total Maximum Daily Load of Biochemical Oxygen Demand (BOD) for the Western Branch of the Patuxent River

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LIST OF ABBREVIATIONS

7Q10	7-day consecutive lowest flow expected to occur on average once every 10 years
BOD	Biochemical Oxygen Demand
CBOD	Carbonaceous Biochemical Oxygen Demand
CWA	Clean Water Act
DNR	Department of Natural Resources
EPA	Environmental Protection Agency
EUTRO5	Eutrophication Module of WASP5
FA	Future Allocation
LA	Load Allocation
MDE	Maryland Department of the Environment
MOS	Margin of Safety
NBOD	Nitrogenous Biochemical Oxygen Demand
NPDES	National Pollutant Discharge Elimination System
SOD	Sediment Oxygen Demand
TMDL	Total Maximum Daily Load
USGS	United States Geological Survey
WASP5	Water Quality Analysis Simulation Program 5
WBEM	Western Branch Eutrophication Model
WLA	Waste Load Allocation
WQLS	Water Quality Limited Segment
WSSC	Washington Suburban Sanitary Commission
WWTP	Waste Water Treatment Plant

PREFACE

Section 303(d) of the federal Clean Water Act directs States to identify and list waters, known as water quality limited segments (WQLS), in which currently required pollution controls are inadequate to achieve water quality standards. For each WQLS, the State is to establish a Total Maximum Daily Load (TMDL) of the specified substance that the waterbody can receive without violating water quality standards.

The Western Branch of the Patuxent River was identified on the State's 1996 list of WQLSs because of low dissolved oxygen. Although recent data shows that the dissolved oxygen standard violations in the Western Branch are minor and infrequent, it is suspected that the violations could increase in both severity and frequency in the future. The cause of these violations was initially suspected to be nutrients. Subsequent investigation, however, determined that biochemical oxygen demand (BOD) is the dominant cause of the low dissolved oxygen concentrations. This report documents the proposed establishment of a TMDL for the Western Branch to improve dissolved oxygen concentrations.

Once approved by the United States Environmental Protection Agency (EPA), the TMDL will be reflected in the State's Continuing Planning Process. In the future, the established TMDL will support regulatory and voluntary measures needed to protect water quality in the Western Branch of the Patuxent River

EXECUTIVE SUMMARY

This document establishes a Total Maximum Daily Load (TMDL) that addresses low dissolved oxygen concentrations in the Western Branch of the Patuxent River. The water quality goal of the TMDL is to establish allowable BOD inputs at a level that will ensure the maintenance of the dissolved oxygen standard.

The TMDL was developed using the WASP5 water quality model. The model was used to determine what was causing the low dissolved oxygen: nutrients or BOD. It was determined that BOD was the dominant factor. The model was also used to investigate seasonal variations in stream conditions and to establish margins of safety that are environmentally conservative. Load allocations were determined for distributing allowable loads between point and nonpoint sources.
The allocation of BOD for nonpoint sources was based on observed field values. The point source allocation was based on the current maximum National Pollutant Discharge Elimination System (NPDES) permit limits at the Western Branch WWTP, as well as another smaller point source in the Charles Branch watershed. This watershed drains to the Western Branch near its confluence with the Patuxent River. The TMDL for BOD in Western Branch is 84,840 lb/month[1]. This TMDL is seasonal and applies during the period from April 1 to October 15.

Two factors provide assurance that this TMDL will be implemented. First, NPDES permits will be written to be consistent with the load allocations in the TMDL. Second, Maryland has adopted a watershed cycling strategy, which will ensure that future water quality monitoring and TMDL evaluations are routinely conducted.

1 This BOD TMDL is based on the assumption that the Western Branch WWTP will continue to meet its current NPDES discharge limits for nitrogen, ammonia, and phosphorus, and that the Croom Manor WWTP will continue to meet its NPDES limit for nitrogen. In addition, this TMDL indicates that water quality standards will be met if dissolved oxygen concentrations from the Western Branch WWTP are increased to 7 mg/l. Specific NPDES permit limits for the Western Branch WWTP and the Croom Manor WWTP will be determined in the context of the NPDES permit renewal process.

INTRODUCTION

The Clean Water Act (CWA) Section 303(d)(1)(C) and federal regulation 40 CFR §130.7(c)(1) direct each State to develop Total Maximum Daily Loads (TMDL) for all impaired waters on the Section 303(d) list. States must consider seasonal variations and must include a margin of safety to account for uncertainty in the monitoring and modeling processes. A TMDL reflects the total pollutant loading of the impairing substance a waterbody can receive and still meet water quality standards.

The Western Branch River (hereafter referred to as "Western Branch") was first identified on the 1996 303(d) list submitted to EPA by the Maryland Department of the Environment (MDE). It was listed as being impaired by nutrients. The impairment consisted of low dissolved oxygen concentrations found near the confluence of the Western Branch and the Patuxent River. The Western Branch is designated as a Use I water according to the Code of Maryland Regulations 26.08.02. The dissolved oxygen standard for a Use I water is 5.0 mg/l. This document demonstrates that the impairment is principally due to biochemical oxygen demand (BOD) in the stream, instead of nutrients, and describes the development of a TMDL for BOD in the Western Branch.

DESCRIPTION OF THE WATERSHED

The Western Branch River is a tributary of the Patuxent River, located in Prince George's County, Maryland (Figure 1). The mainstem of the river is approximately 20 miles long. The watershed of the Western Branch has an area of approximately 71,420 acres. As shown in Figure 2, the predominant land use in the watershed, based on 1994 Maryland Office of Planning information, is forest comprising 31,100 acres or 44% of the total area, with urban at 21,970 acres or 31%, and various kinds of agricultural land uses at 18,180 acres or 25%. The upper free-flowing portion of the Western Branch traverses both urban and forest lands. The lower, tidal portion enters the Patuxent River near Mt. Calvert in the oligohalene salinity zone. Much of the Western Branch's tidal portion is classified as piedmont shallow fresh marsh. Depths of the river range from about 1 to 2 feet in the headwaters to 3 or 4 feet in the tidal zone prior to the river's confluence with the Patuxent River.

The upper portion of the Western Branch watershed travels through steep slopes with medium to high stream velocities. The lower portion below Upper Marlboro is a slow flowing system. The lower portion of the drainage basin is generally flat, and the soils are typically classified as sandy or loamy. As a consequence of the generally flat topography and the sandy soils, stream velocities in this portion of the river are minimal. Tidal currents in the lower river are extremely weak and variable. A diffuse head of tide is located near the Route 301 bridge below Upper Marlboro. Bottom sediments in the river are typically found to be firm muds and clays of moderate to high compaction, locally mixed with sand and other deposits.

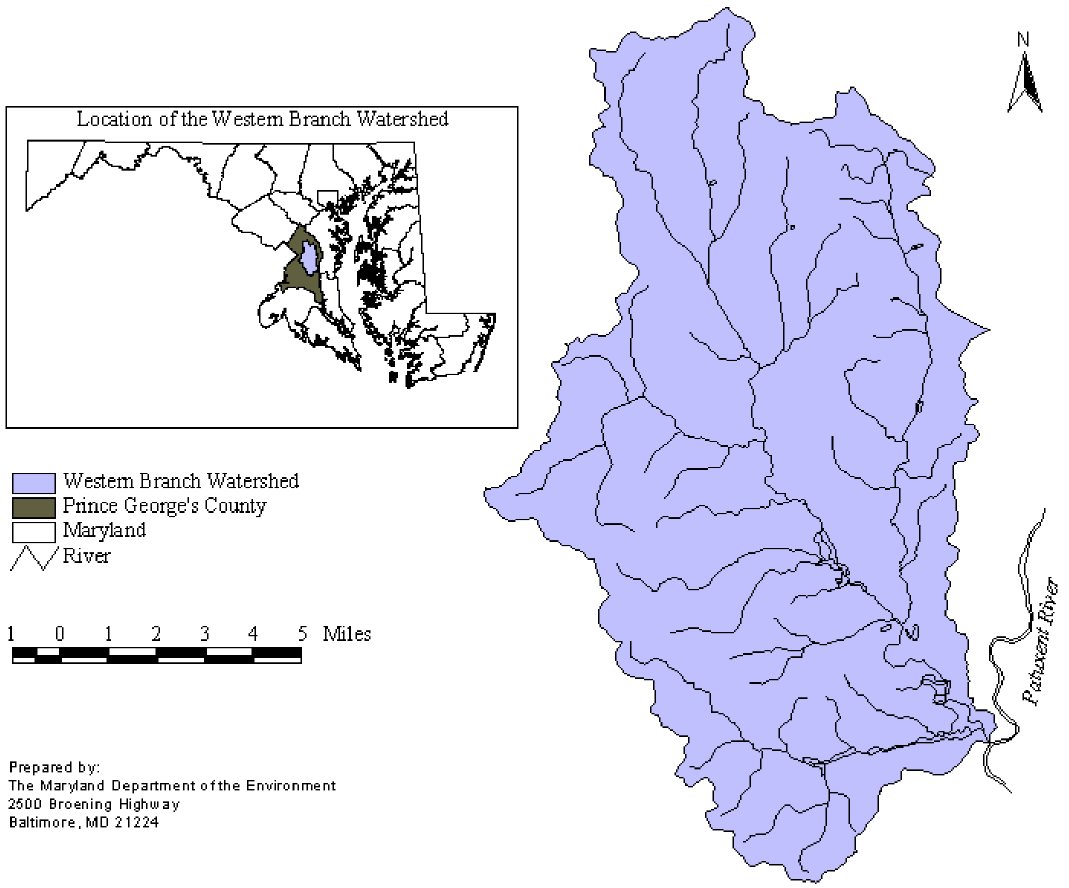

Figure 1: Location of the Western Branch Drainage Basin, within Prince George's County, Maryland

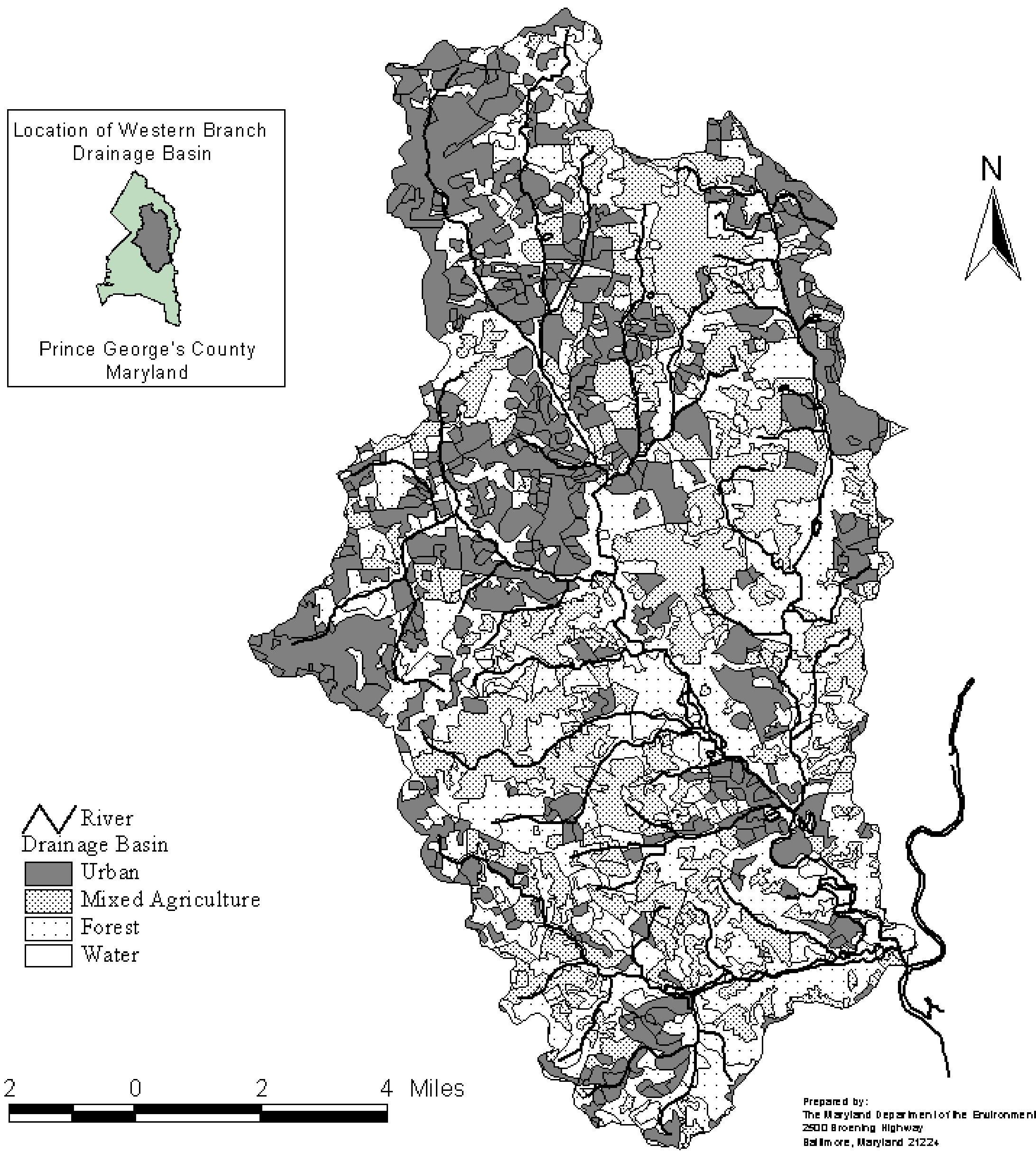

Figure 2: Land use in the Western Branch Drainage Basin, Price George's County, Maryland

WATER QUALITY CHARACTERIZATION

Western Branch Water Quality

Two historical water quality sampling stations, WXT0001 and WXT0045 were used to characterize the existing water quality in the portion of Western Branch where the impairment is located. Figure 3 shows the location of water quality sampling sites, a United States Geological Survey (USGS) flow gage, and other geographic points of interest in the watershed. Water chemistry data has been collected by Maryland Department of Natural Resources (DNR) and Maryland Department of the Environment (MDE) since September 1985 at station WXT0045 and since September 1990 at station WXT0001. The water quality of six parameters, dissolved oxygen, chlorophyll *a*, dissolved inorganic nitrogen (ammonia, nitrite, and nitrate), and ortho-phosphate collected at these stations were examined, for the period between August 1990 and December 1998

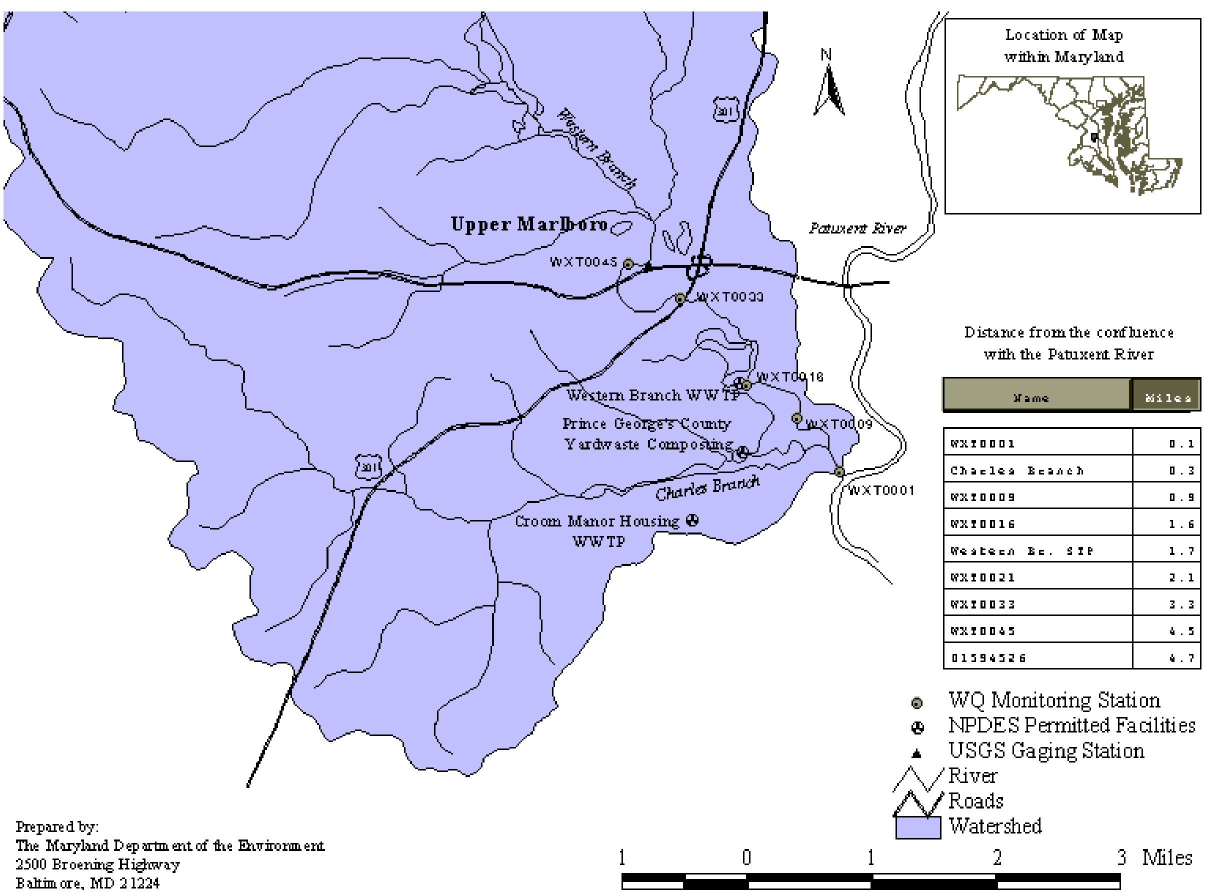

Figure 3: Location of water quality monitoring stations, and other points of interest

The important issues for this portion of Western Branch are the amount of nutrients and BOD entering the system at the upper water quality monitoring station (WXT0045) and the dissolved oxygen concentrations at the lower water quality station (WXT0001). Figure 4 shows the measured dissolved oxygen concentrations at station WXT0001, downstream from the Western Branch Wastewater Treatment Plant (WWTP). Although the problem is not currently severe, the data show that dissolved oxygen levels occasionally fall below the numeric criteria of 5.0 mg/l during summer months. As recently as June 1998, the dissolved oxygen level fell to within 0.2 mg/l of the water quality standard. Figure 5 shows the chlorophyll *a* concentrations observed at station WXT0001 occasionally peaking at more than 70 µg/l during late summer months.

Figure 6 shows the dissolved inorganic nitrogen measured at station WXT0045. Dissolved inorganic nitrogen concentrations generally average about 0.5 mg/l, with one peak as high as 1.0 mg/l. Figure 7 shows the ortho-phosphate concentrations at station WXT0045 generally varying between 0.005 and 0.06 mg/l.

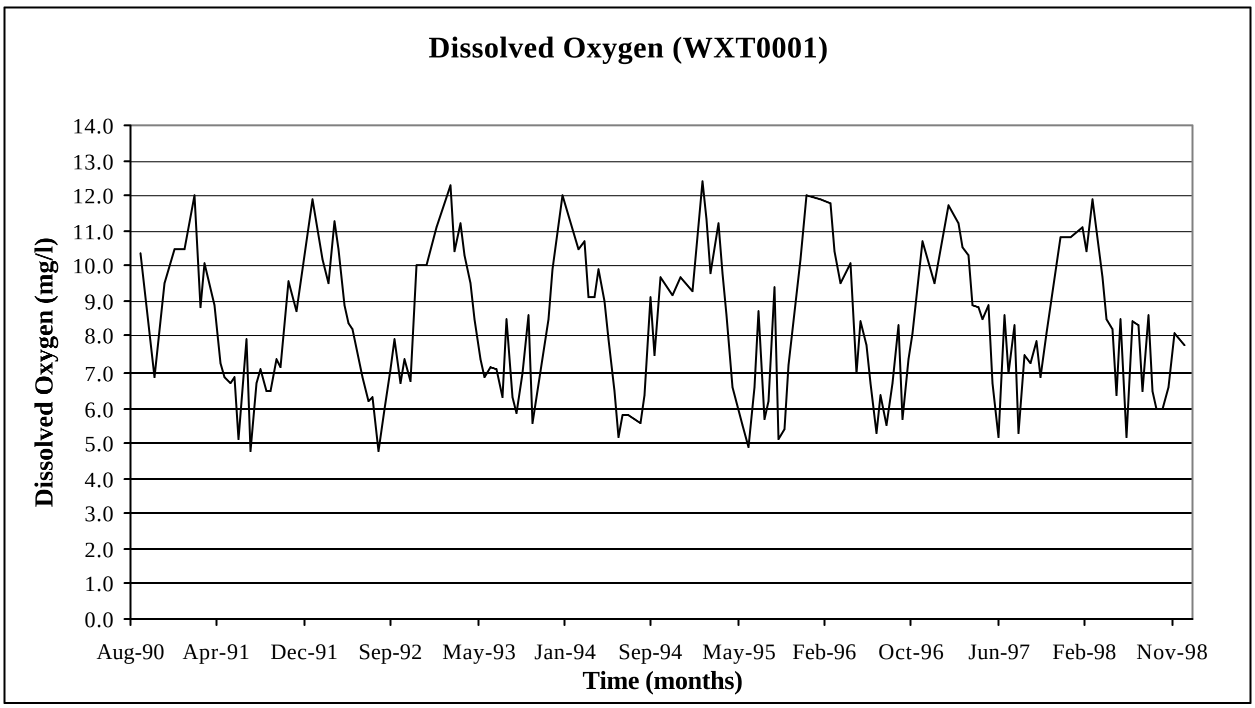

Figure 4: Dissolved oxygen concentrations at water quality station WXT0001

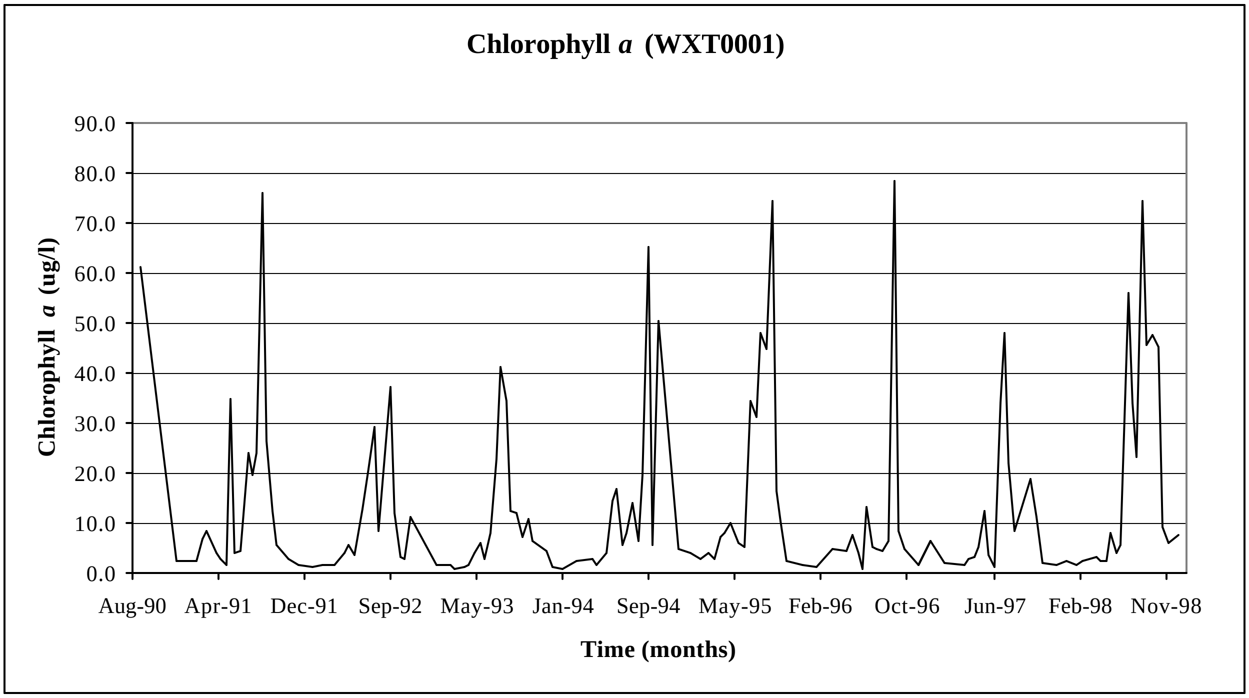

Figure 5. Chlorophll *a* concentrations at water quality station WXT0001

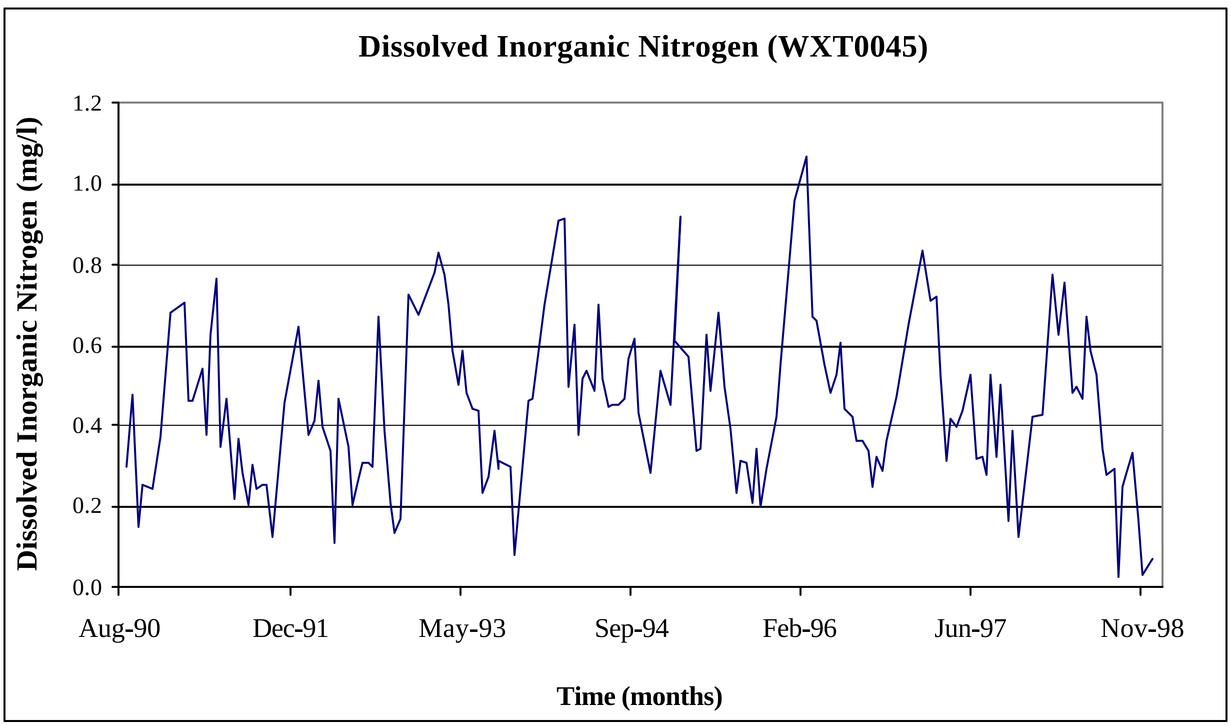

Figure 6: Dissolved inorganic nitrogen concentrations at water quality station WXT0045

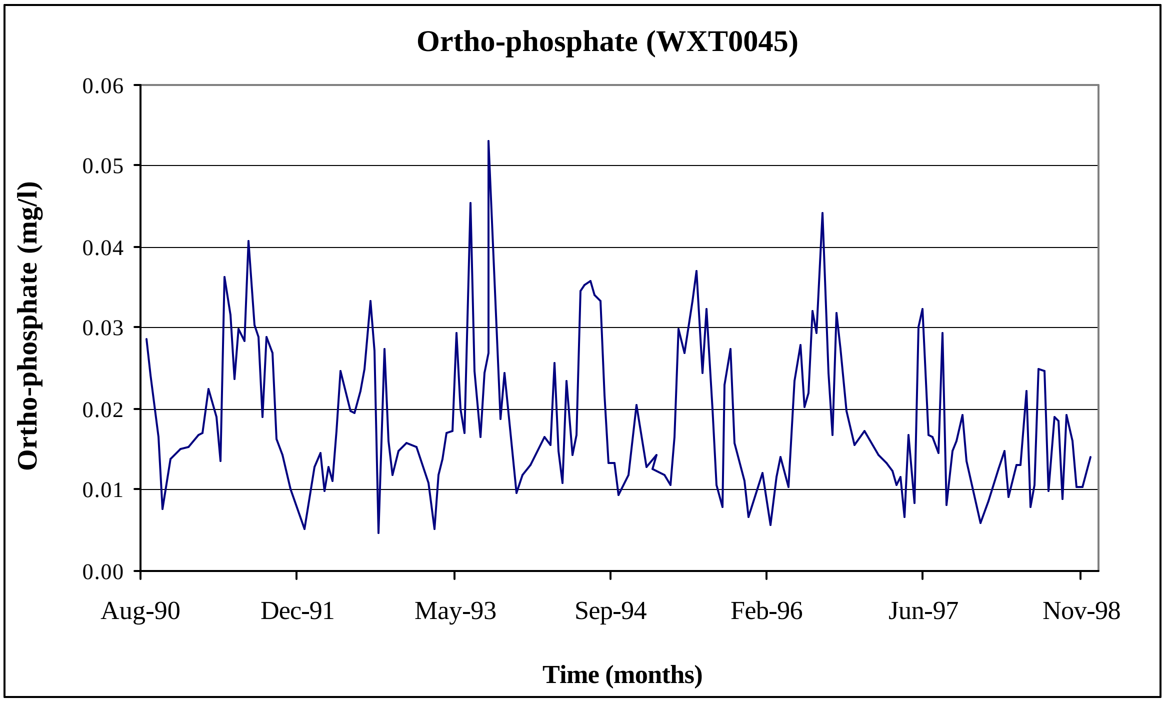

Figure 7: Ortho-phosphate concentrations at water quality station WXT0045

Sources of the Impairing Substance

The primary substances of concern in this watershed are nutrients and BOD. Nutrients stimulate algae growth, which in turn die and start decaying in the sediment layer, and consume oxygen. BOD is a composite term that describes the consumption of oxygen through the oxidation of carbon and nitrogen by bacteria in the water. The sources of nutrients and BOD include both point and nonpoint source loads. In the Western Branch there is one dominant point source, the Western Branch WWTP, contributing most of the nutrients and BOD to the system, during low flows. Two other smaller point sources, Croom Manor Housing WWTP and Prince George's County Yardwaste Composting Facility also contribute small amounts of nutrients and BOD to the system. The point source values used in this document come from discharge monitoring reports for each of the WWTPs.

The majority of the nonpoint source loads of nutrients and BOD enter the system at the upstream boundary located at water quality station WXT0045. The Charles Branch, a small tributary of the Western Branch, also contributes minimal loads to the system. The nonpoint source loads are based on in-stream water quality monitoring data. The in-stream data accounts for atmospheric deposition to the land, nonpoint source runoff, and nutrient infiltration from septic tanks. While this document addresses both nutrients and BOD, the TMDL reflects limits on BOD only, because as will be discussed in the modeling results, BOD is the dominant impairing substance.

In addition to accounting for the sources of the substances of concern, the processes that deplete dissolved oxygen should also be considered. These processes include those that consume oxygen (sinks) as well as those that generate oxygen (sources). These processes and some additional factors are presented in Figure 8. As mentioned before, BOD reflects the amount of oxygen consumed through two processes: carbonaceous biochemical oxygen demand (CBOD) and nitrogenous biochemical oxygen demand (NBOD). CBOD is the reduction of organic carbon material to its lowest energy state, CO_2, through the metabolic action of microorganisms (principally bacteria). NBOD is the term for the oxygen required for nitrification, which is the biological oxidation of ammonia to nitrate. The BOD values seen throughout this document represent the amount of oxygen consumed by the oxidation of carbonaceous and nitrogenous waste materials over a 5-day period, at 20 ^oC. This is referred to as a 5-day, 20 ^oC BOD and is the standard reference value utilized internationally by both design engineers and regulatory agencies. The 5-day BOD represents primarily consumption of carbonaceous material and minimal nitrogenous material. The ultimate BOD represents the total oxygen consumed by carbonaceous and nitrogenous material, over an unlimited length of time.

Another factor influencing dissolved oxygen concentrations is the sediment oxygen demand (SOD). As with BOD, SOD is a combination of several processes. Primarily it is the aerobic decay of organic materials that settle to the bottom of the stream. The organic materials can some from several sources. One, as mentioned in reference to nutrients, is decaying algae. Another is dead leaves and other debris, which is swept into the system from the land surfaces and upper portions of the watershed during rain events. Because SOD captures the effects of decaying organic material deposited during storm events, it can also indirectly account for the effects of high stream flow events. All of the dissolved oxygen sources and sinks make up the dissolved oxygen balance, and are considered in the model water quality kinetics. For more information, see Appendix A.

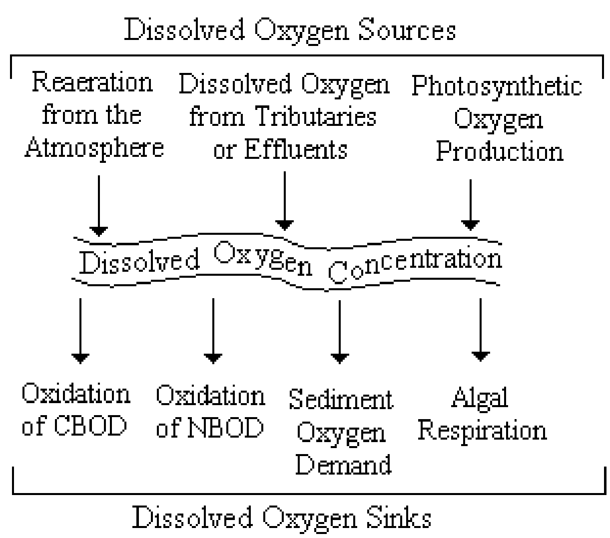

Figure 8: Sources and sinks for dissolved oxygen in the river

WATER QUALITY IMPAIRMENT

The Western Branch impairment consists of minor seasonal violations in the dissolved oxygen standard for Use I waters and frequent borderline low dissolved oxygen levels at station WXT0001, as indicated by monitoring data shown in Figure 4. As it currently stands, these minor and infrequent dissolved oxygen standard violations would not be a major cause of concern. However, if nonpoint source loads increase in the future, and the Western Branch WWTP continues to increase its flows to the stream, it is possible that these violations could increase in both severity and frequency. Development of a TMDL at this point will minimize further degradation of the waterbody.

In the 1996 303(d) list, the cause of the impairment was presumed to be nutrients. However, as will be discussed in greater detail below, subsequent modeling has determined that BOD is the dominant cause of the low dissolved oxygen impairment.

TARGETED WATER QUALITY GOAL

The overall objective of the development of the TMDL in Western Branch is to determine the maximum allowable BOD inputs from point and nonpoint sources that will allow for the maintenance of dissolved oxygen standards. The development of the TMDL for the Western Branch is intended to assure that dissolved oxygen concentrations remain above a minimum of 5.0 mg/l in the lower reaches of the Western Branch system. This dissolved oxygen goal is based on specific numeric criteria for Use I designated waters set forth in the Code of Maryland Regulations 26.08.02.

TOTAL MAXIMUM DAILY LOADS AND ALLOCATIONS

This section describes how the TMDL and load allocations for point and nonpoint sources were developed for the Western Branch. The first section describes the modeling framework for simulating water quality constituent interactions and hydrology. The second and third sections summarize the scenarios that were explored using the model. The assessment investigates water quality responses assuming different stream flow conditions and load allocations. The fourth and fifth sections present the modeling results in terms of TMDLs, and allocate the TMDL between point sources and nonpoint sources. The sixth section explains the rationale for the margin of safety and remaining future allocation. Finally, the pieces of the equation are combined in a summary accounting of the TMDL.

Analysis Framework

The computational framework, or model, chosen for determining the TMDL of Western Branch was the Water Quality Analysis Simulation Program 5.1 (WASP5.1). WASP5.1 provides a generalized framework for modeling contaminant fate and transport in surface waters (Di Toro *et al*., 1983). It is a very versatile program, capable of simulating time-variable or steady state conditions, one, two or three-dimensional systems, and linear or non-linear kinetic water quality problems. It can be used in studies that include biochemical oxygen demand and dissolved oxygen dynamics, nutrients and eutrophication, and organic chemical and heavy metal contamination. EUTRO5.1 is the component of WASP5.1 that is applicable to modeling eutrophication. It was used to develop the water quality model of the Western Branch system, or Western Branch Eutrophication Model (WBEM). For more information on WASP5.1, see Appendix A.

The spatial domain represents the portion of the watershed that is included in the model. The WBEM's spatial domain extends from the confluence of the Western Branch and the Patuxent River for approximately 3.5 miles upstream along the mainstem of the Western Branch to station WXT0045 (see Figure 9). Station WXT0045 is the upper boundary of the model's spatial domain, and the confluence with the Patuxent is the lower boundary. The model's spatial domain does not include the entire length of the Western Branch River; rather, it focuses on the area where the localized dissolved oxygen impairment occurs. Figure 9 also includes the location of several other key inputs to the model as well as the model segmentation.

There are two nonpoint source loads entering the system. The majority of the nonpoint source loads coming into the system are assumed to enter at station WXT0045. All loads from the upper portions of the Western Branch watershed that are not included in the modeling domain are assumed to be captured at this station. A second nonpoint source load, the Charles Branch, enters the Western Branch just before its confluence with the Patuxent mainstem. Both nonpoint source loads include atmospheric deposition, loads from septic tanks, and loads coming from urban development, agriculture, and forest land. The freshwater flows used in the model were obtained from the USGS gage located in Upper Marlboro (01594526), very close to station WXT0045.

There are three NPDES permitted point sources in the portion of the watershed downstream of station WXT0045. The only direct point source discharge into the system is the Western Branch WWTP. The other two permittees, Croom Manor Housing WWTP and Prince George's County Yardwaste Composting Facility, discharge into the Charles Branch. Croom Manor Housing is treated as a distinct load entering the Western Branch at the same location as the Charles Branch. The Prince George's County Yardwaste Composting facility has an individual stormwater permit, and discharges stormwater. During low-flow conditions, it is assumed there has been very little rainfall, and therefore there are no loads coming from the composting facility. During average or high flow conditions, it was assumed there would be loads coming from the composting facility.

The 5-day BOD value seen throughout this document represents primarily consumption of carbonaceous material and minimal nitrogenous material. EUTRO5.1 models nitrogen as a separate variable. Therefore, the consumption of oxygen due to nitrogenous material is accounted for within the model.

The WBEM was calibrated with December 1997 data collected by MDE's Field Operations Program staff. Detailed analysis and results of the calibration of the model can be seen in Appendix A. The model was then post-audited with summer data provided by the Washington Suburban Sanitary Commission (WSSC). The results of this post-audit can also be seen in Appendix A.

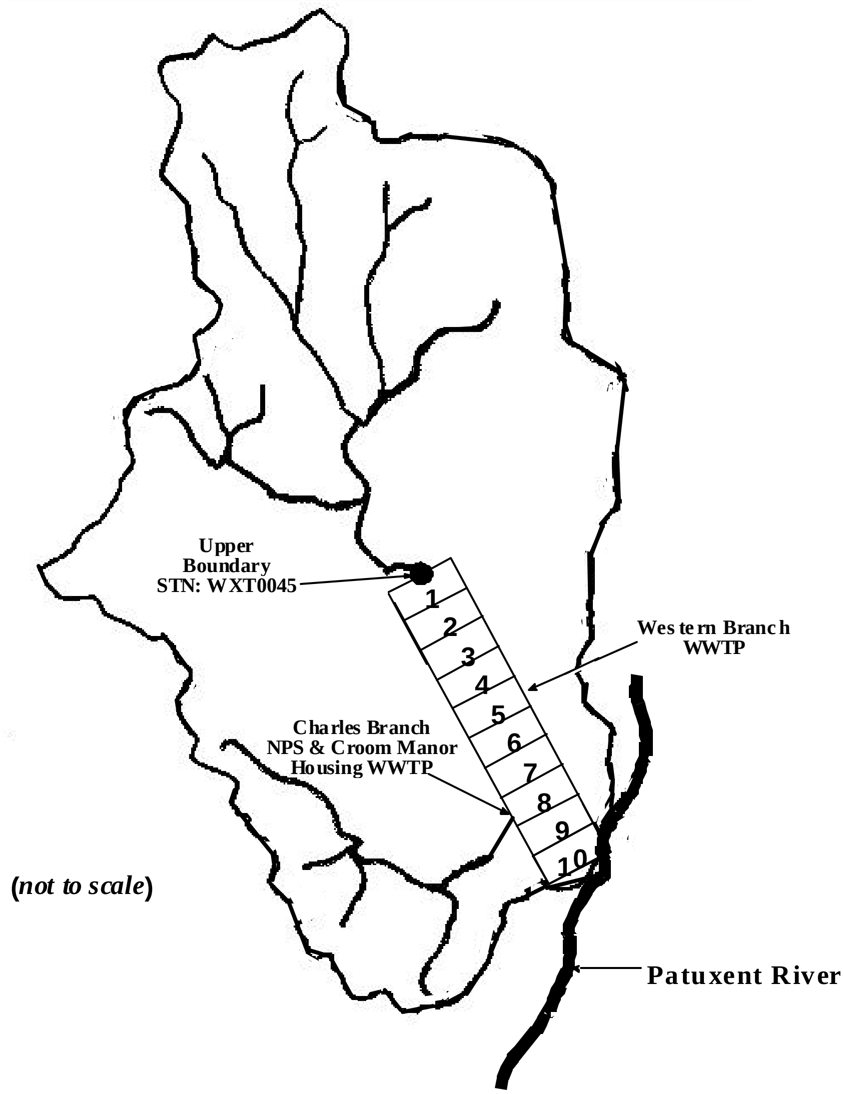

Figure 9: Modeling domain, segmentation, point and nonpoint source location.

Scenario Descriptions

To project the water quality response of the system the model was applied to several different scenarios under various nutrient and BOD loading conditions and stream flow conditions. By modeling different loading conditions, the scenarios identified which water quality constituent was principally responsible for the low dissolved oxygen in the river. By modeling several stream flow conditions, the scenarios simulate seasonality, which is a necessary element of the TMDL development process.

The scenarios are grouped into three categories according to *beginning condition scenarios, impairing substance determination scenarios,* and *final condition scenarios*. The *beginning condition scenarios* represent the future conditions of the system with no reductions in point or nonpoint source loads. The *impairing substance determination scenarios* analyze the sensitivity of the system to several different nutrient and BOD loading conditions, which show BOD is the primary factor behind the low dissolved oxygen concentrations. The *final condition scenarios* represent the projected maximum point and nonpoint source loads.

Beginning Condition Scenarios

The first scenario represents the system during summer low-flow conditions. At the upper boundary of the Western Branch, a flow of 3 cfs was used, which represents the 7-day consecutive lowest flow expected to occur every 10 years, known as the 7Q10 flow. The flow from Charles Branch was calculated as a portion of the Western Branch flow based on the relative drainage area size of the two watershed basins. The nonpoint source loads reflect values observed in the Western Branch watershed during periods of low-flow. The nonpoint source BOD concentration was derived from dry weather data analysis performed by Prince George's County (Cheng). The point source loads were computed under the assumption that the Western Branch WWTP and Croom Manor WWTP would be discharging at their current monthly maximum National Pollutant Discharge Elimination System (NPDES) permit limits. Because this scenario represents summer conditions, summer limits were used where applicable. The point source loads from the Prince George's County Yardwaste Composting facility were assumed to be zero, because during 7Q10 conditions, there would be no rainfall to produce a load.

The second scenario represents the system during winter conditions. Low dissolved oxygen concentrations were not expected to occur in the winter. However, to rule out winter as a critical period, the worst possible conditions that could occur in the winter were examined in this scenario. Analysis of the flow data at the USGS station in Upper Marlboro showed that the 1994-1995 hydrologic year was a relatively low-flow year. To calculate worst case conditions in the winter, flow from October 16, 1994 to March 31, 1995 was averaged and used in this scenario (76 cfs). Again, the flow from Charles Branch was estimated as a portion of the flow in Western Branch based on relative drainage area sizes. The nonpoint source loads reflect values observed at water quality monitoring stations during the period October through March. The nonpoint source BOD concentration was derived from wet weather data analysis performed by Prince George's County (Cheng). The point source loads from Western Branch WWTP and Croom Manor WWTP were computed under the same assumption as scenario one; however, winter flows and concentrations were used. At Prince George's County Yardwaste Composting Facility, the load was calculated by multiplying the highest expected runoff volume by the highest BOD value measured between 3/94 to 5/98.

Impairing Substance Determination Scenarios

The next three scenarios constitute sensitivity analyses to determine what substances to control to ensure the dissolved oxygen standard is achieved. The third scenario was developed to estimate the effects of reduced nitrogen on the summer critical conditions. The nonpoint source loads were the same as for scenario one. The point source loads were similar to scenario one; however, the amount of nitrogen discharged from the Western Branch WWTP was reduced by 75% to see how this change would affect the dissolved oxygen levels.

The fourth scenario was developed to estimate the effects of reduced phosphorus on the summer critical conditions. The nonpoint source loads were the same as for scenario one. The point source loads were similar to scenario one; however, the amount of phosphorus discharged from the Western Branch WWTP was reduced by 75% to see how this change would affect the dissolved oxygen levels.

The fifth scenario was developed to estimate the effects of reduced BOD on the summer critical conditions. The nonpoint source loads were the same as for scenario one. The point source loads were similar to scenario one; however, the amount of BOD discharged from the Western Branch WWTP was reduced by 75% to see how this change would affect the dissolved oxygen levels.

Final Condition Scenarios

For the final condition scenarios, it is very important that the dissolved oxygen concentrations do not go below the standard of 5 mg/l. The WBEM calculates the daily average dissolved oxygen concentrations in the stream, which may be higher than the minimum dissolved oxygen concentration that occurs during a 24-hour period. The reason is the diurnal dissolved oxygen effect due to photosynthesis and respiration of algae. The photosynthetic process centers about the chlorophyll within algae, which utilizes 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. At the same time, however, the algae require oxygen for respiration.

Minimum values of dissolved oxygen usually occur in the early morning predawn 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 to 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 events. The WBEM is also capable of calculating the minimum dissolved oxygen concentration for each segment, by subtracting half the diurnal range from the average.

The dissolved oxygen concentrations plotted for scenarios six and seven are the minimum concentrations, as calculated by the model.

The sixth scenario determines the effects of increased dissolved oxygen effluent concentrations at the Western Branch WWTP. The nonpoint source loads were the same as for scenario one. The point source loads were the same as scenario one; however, the dissolved oxygen concentration in the effluent discharged from the Western Branch WWTP was increased to 7 mg/l.

The seventh scenario shows the effects of the proposed final solution, including a margin of safety and a future allocation. The nonpoint source loads were increased from scenario one to include a future allocation for upstream sources, and a 5% margin of safety. The point source loads were similar to scenario 6, however, an additional BOD margin of safety was added at the Western Branch WWTP and Croom Manor WWTP. The margin of safety was calculated as 10% of the difference between the weekly and monthly limits at the two WWTPs. The point and nonpoint source loads for all scenarios can be seen in Table 1.

Table 1: Point and nonpoint source flows and loads used in the model scenario runs

Scenario		1	2	3	4	5	6	7
Nonpoint Source Loads								
BOD_5	*lb/day*	34.4	872.2	34.4	34.4	34.4	34.4	190.9
Total Nitrogen	*lb/day*	16.4	427.3	16.4	16.4	16.4	16.4	16.4
Total Phosphorus	*lb/day*	1.8	32.0	1.8	1.8	1.8	1.8	1.8
Flow	*cfs*	3.20	80.93	3.20	3.20	3.20	3.20	3.20
Point Source Loads								
BOD_5	*lb/day*	2502.5	12277.1	2502.5	2502.5	626.0	2502.5	2502.5
Total Nitrogen	*lb/day*	751.3	4039.7	188.2	751.3	751.3	751.3	751.3
Total Phosphorus	*lb/day*	250.3	337.0	250.3	62.6	250.3	250.3	250.3
Flow	*mgd*	30.0042	35.1037	30.0042	30.0042	30.0042	30.0042	30.0042
BOD_5 Margin of Saftey	*lb/day*	0.0	0.0	0.0	0.0	0.0	0.0	134.7

Model Results

Beginning Condition Scenarios

1. *Summer Flow*: Assumes 7-day consecutive lowest flow expected to occur once every 10 years. Assumes summer low-flow nonpoint source concentrations. Assumes current monthly summertime NPDES permitted flows and concentrations at both of the WWTPs.

2. *Winter Flow*: Assumes average winter stream flow conditions. Assumes winter average nonpoint source concentrations. Assumes current monthly winter NPDES permitted flows and concentrations at both of the WWTPs. Assumes maximum flows and concentrations at the composting facility.

The first scenario represents the critical conditions of the system during summer low stream flow. As seen in Figure 10, the dissolved oxygen level goes below the water quality standard of 5 mg/l. The results of the second scenario, also seen in Figure 10, show the stream system to have a higher dissolved oxygen concentration during winter low-flow conditions. Scenario 2 also shows that even with a very high BOD load coming from the composting facility, the dissolved oxygen standard is still being met. For more results from scenarios 1 and 2, see Appendix A.

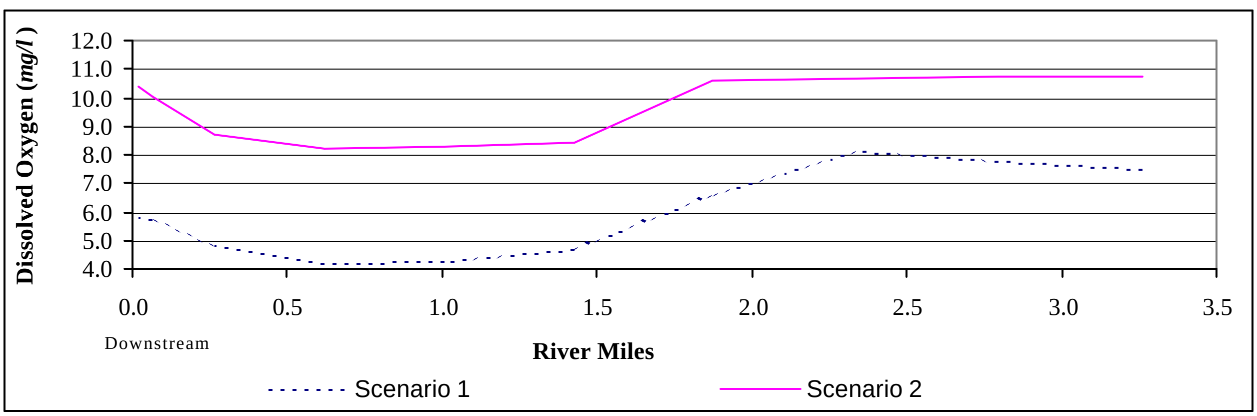

Figure 10: Results of model scenario runs 1 and 2 for dissolved oxygen

Determination Scenarios

3. *Reduced Nitrogen*: Assumes 7-day consecutive lowest flow expected to occur once every 10 years. Assumes corresponding summer low-flow nonpoint source concentrations. Assumes current monthly summertime NPDES permitted flows and concentrations from both of the WWTPs. The effluent concentration of nitrogen from Western Branch WWTP is reduced by 75 %.

4. *Reduced Phosphorus*: Assumes 7-day consecutive lowest flow expected to occur once every 10 years. Assumes corresponding summer low-flow nonpoint source concentrations. Assumes current monthly summertime NPDES permitted flows and concentrations from both of the WWTPs. The effluent concentration of phosphorus from Western Branch WWTP is reduced by 75%.

5. *Reduced BOD*: Assumes 7-day consecutive lowest flow expected to occur once every 10 years. Assumes corresponding summer low-flow nonpoint source concentrations. Assumes current monthly summertime NPDES permitted flows and concentrations from both of the WWTPs. The effluent concentration of BOD from the Western Branch WWTP is reduced by 75%.

The results of scenario three indicate that, even with the point source nitrogen loads decreased by half, the water quality standard for dissolved oxygen is just barely met at all locations along the portion of the Western Branch that was modeled. The model results indicate that the system is not highly sensitive to changes in nitrogen. Moreover, the Western Branch WWTP already has very strict nitrogen concentration limits on its discharge effluent. Given the relative insensitivity to further reductions in nitrogen, it would be inefficient to reduce these loads to the levels used in scenario three. Thus, further nitrogen reduction is not an effective way of achieving the dissolved oxygen water quality standard.

The results of scenario four show that a reduction in point source phosphorus has no effect on the dissolved oxygen concentration in the river; the system is not sensitive to changes in phosphorus. Given this complete insensitivity to further reductions in phosphorus, phosphorus reduction is not an effective way of achieving the dissolved oxygen water quality standard.

The fifth scenario shows that a reduction in BOD will cause the water quality standard for dissolved oxygen to be comfortably met at all locations within the Western Branch modeling domain. These results indicate that BOD is the principal controlling factor of dissolved oxygen in the Western Branch. The model results for scenarios 3, 4, and 5, showing nitrogen, phosphorus, BOD, and dissolved oxygen can be seen in Figure 11, for more results see Appendix A.

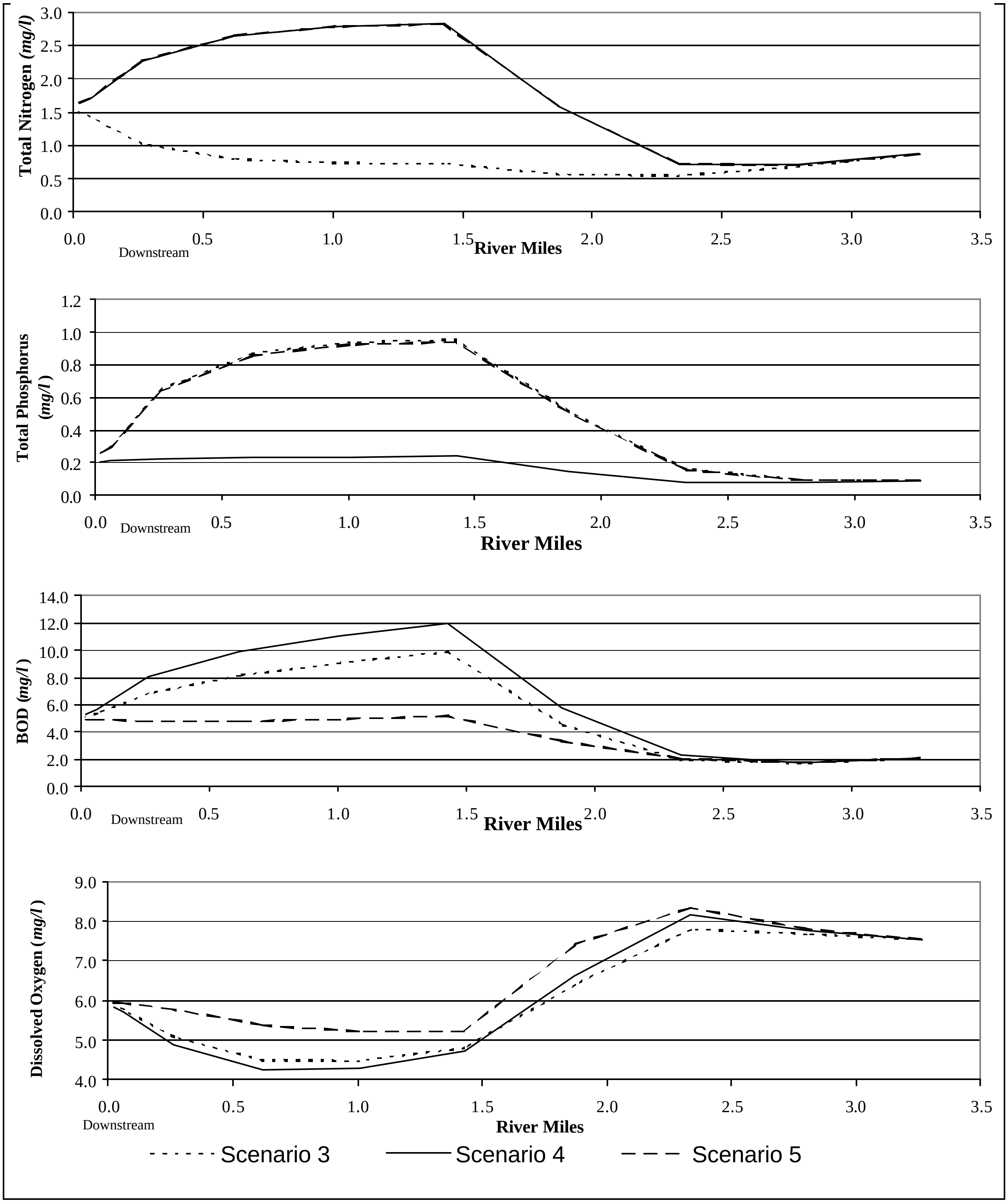

Figure 11: Results of model scenarios 3, 4, and 5 for total nitrogen, total phosphorus, BOD, and dissolved oxygen

Final Solution Scenarios

6. *Increased Effluent Dissolved Oxygen*: Assumes 7-day consecutive lowest flow expected to occur once every 10 years. Assumes corresponding summer low-flow nonpoint source concentrations. Assumes current monthly summertime NPDES permitted flows and concentrations from both of the WWTPs. Assumes a dissolved oxygen effluent concentration of 7.0 mg/l being discharged from the Western Branch WWTP.

7. *Increased Effluent Dissolved Oxygen with MOS*: Assumes 7-day consecutive lowest flow expected to occur once every 10 years. Assumes corresponding summer low-flow nonpoint source concentrations plus a future allocation and a margin of safety. Assumes current monthly summertime NPDES permitted flows and concentrations from both of the WWTPs, plus a margin of safety. Assumes a dissolved oxygen effluent concentration of 7.0 mg/l being discharged from the Western Branch WWTP.

As can be seen in Figure12, when the dissolved oxygen level in the Western Branch WWTP effluent is set to 7.0 mg/l, the dissolved oxygen standard is maintained along the length of the modeling domain in the Western Branch River, including a dissolved oxygen correction for the diurnal effect. Figure 12 also shows that when a BOD margin of safety and future allocation is added, and the diurnal dissolved oxygen effect is accounted for, the dissolved oxygen standard is still met. For further analysis of the model scenario runs, see Appendix A.

In Scenario 7, all water quality standards were met at the 7-day consecutive lowest flow expected to occur once every 10 years. This flow corresponds with the most critical conditions in the system. The model was run with higher flows, and the same point and nonpoint source concentrations that were used in scenario 7, to ensure that in-stream water quality standards were still being met. As seen in Figure 13, when the flow in the system increases, the water quality standards are more than met. The low dissolved oxygen concentrations in the model typically occur in model segment 8. The low dissolved oxygen values seen in Figure 13 occur at that location.

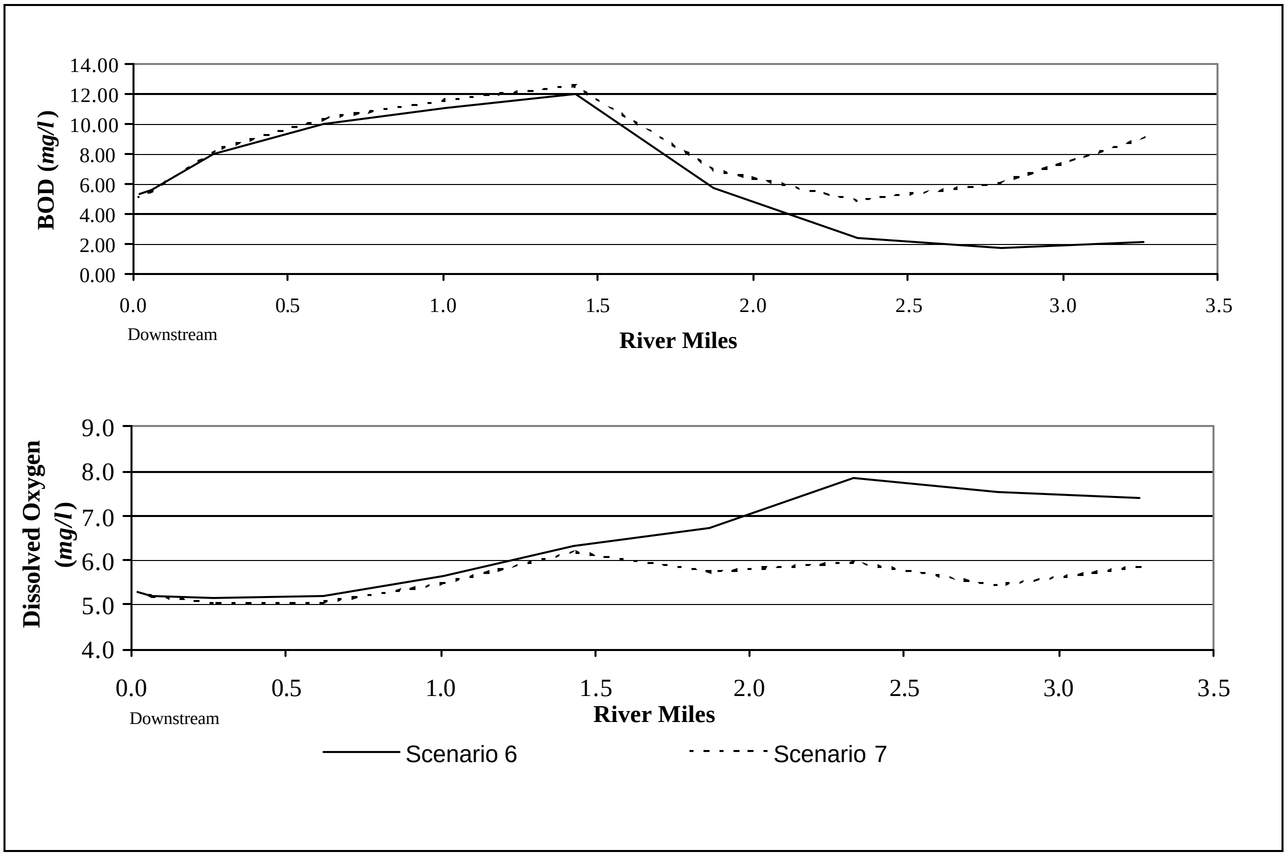

Figure 12: Model results for scenario runs 6 and 7 for BOD and dissolved oxygen

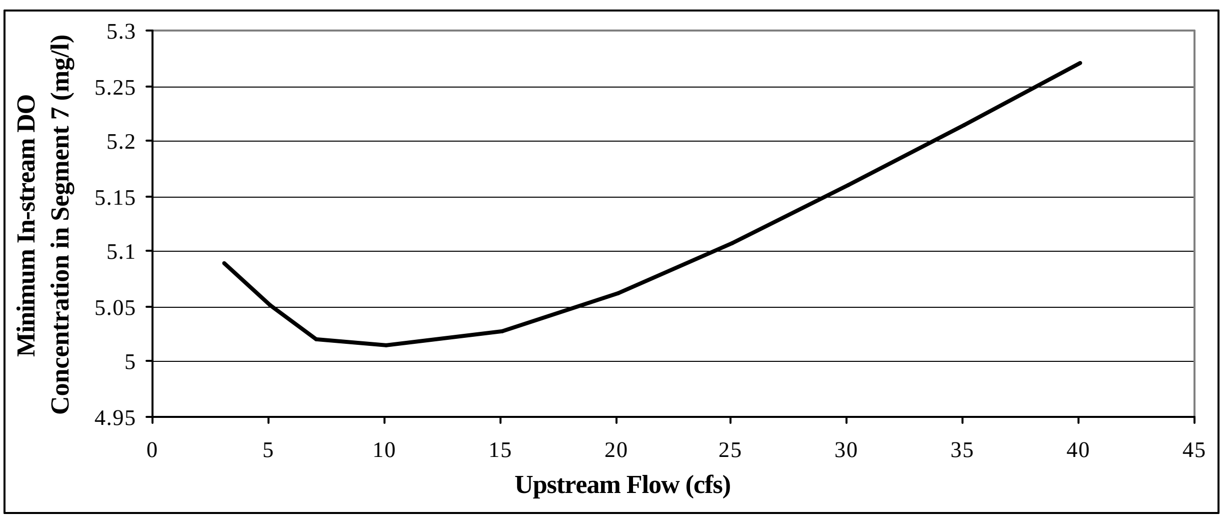

Figure 13: Minimum in-stream dissolved oxygen concentrations in model segment 8, with increasing flows at the upper boundary of the model.

TMDL Loading Cap

The first model scenario showed that the dissolved oxygen standard in the Western Branch is only violated during low stream flow conditions in the summer, when the water temperatures are warmer and there is less water flowing in the system. The second model run indicated that no dissolved oxygen violations are expected during winter conditions. Thus, summer is the critical season for which a TMDL is necessary. The third, fourth, and fifth model scenarios examined the sensitivity of the system to nutrients and BOD, showing that BOD is the principal factor influencing the dissolved oxygen problem in the Western Branch. The sixth model scenario showed that increasing the dissolved oxygen concentrations of the Western Branch WWTP effluent would increase the dissolved oxygen in the river to above the water quality standard. Increasing the dissolved oxygen at the WWTP presents a less expensive solution to the low dissolved oxygen problem than reducing the effluent BOD concentration. The seventh model scenario shows that the dissolved oxygen standard is met with a future allocation and margin of safety. Thus, the modeling analyses indicate that, under future projected conditions with the proposed BOD TMDL, water quality standards are maintained for all flow conditions. The TMDL was calculated for only 7Q10 conditions. Because 7Q10 conditions are only likely to occur during summer months, this TMDL only applies from April 1 to October 15. Model scenario seven represents the final TMDL loading scenario. The resultant TMDL loading for BOD is:

BOD TMDL (April 1 to October 15)   84,840 *lb/month*

The BOD TMDL analysis accounts for observed low-flow nonpoint source nutrient loads associated with groundwater base-flow. These base-flow NPS loads are expected to remain relatively constant in the future due to efforts of nonpoint source BMPs being implemented as part of Maryland's Tributary Strategies.

Additionally, the BOD TMDL analysis accounts for current point source permit limits for nutrients. The analysis also assumes viable future operating assumptions with regard to dissolved oxygen concentrations in the effluent of the WWTPs in the Western Branch watershed, which are detailed in the Load Allocations section below.

It should be noted that the NPDES permit limits for nutrients were established to be protective of water quality downstream of the confluence of the Western Branch and the Patuxent River. The nutrient permit limits at the Western Branch WWTP are near the maximum level of technology. These permit limits represent enforceable controls that are as, or more, restrictive than needed to meet the water quality standards within the Western Branch watershed. Although nutrient TMDLs are not being specified for the Western Branch watershed at this time, MDE may establish nutrient limits in the future for the Western Branch watershed within the context of establishing nutrient limits for the larger Patuxent River watershed.

Load Allocations Between Point Sources and Nonpoint Sources

The point source load allocation for BOD is represented as the current monthly summer loads (based on the NPDES permit) from the Western Branch WWTP and Croom Manor Housing WWTP, assuming maximum design flows and monthly BOD concentration limits. The total monthly load allocation was calculated directly from existing monthly average permit limits multiplied by 30 days. To implement the point source allocations, permit limits will continue to be expressed as monthly average limits and will be calculated by dividing the allocated TMDL monthly load by 30. To ensure that sampling variability issues are addressed, the limits will also require, as a minimum, the same minimum sampling frequencies which are associated with the current permit limits and with historical data.

This load allocation is also based on the understanding that, in addition to the BOD limit of 75,060 lb/month, the Western Branch WWTP will discharge at a dissolved oxygen concentration of no less than 7.0 mg/l. NPDES permit limits for nitrogen and phosphorus at the two WWTPs were developed to be protective of dissolved oxygen standards far downstream in the Patuxent Estuary. These limits are as, or more restrictive than necessary to meet the standards within the Western Branch. The summer limits at the Western Branch WWTP (4/1 – 10/15) are an average of 3.0 mg/l of total nitrogen and 2.0 mg/l ammonia as nitrogen over a month and an average of 1.0 mg/l of phosphorus over a month. The summer limits at the Croom Manor WWTP (6/1 – 10/31) are an average total Kjeldahl nitrogen of 5.0 mg/l over a month. It is therefore not necessary to set a TMDL for nitrogen or phosphorus, at this time.

The in-stream concentration of BOD from nonpoint sources is estimated to be 2.0 mg/l. This is a representative value obtained from dry weather sampling and data analysis in the Western Branch watershed during the period 1995 to 1998 (Cheng). The 2.0 mg/l concentration was multiplied by the 7Q10 flow (3 cfs) at the upper boundary of the Western Branch and the Charles Branch to produce the nonpoint source load allocations for the TMDL. The low-flow nonpoint source loads are attributable to base-flow contributions. The nonpoint source loads that were assumed in the model account for both “natural” and human-induced components. Ideally one would separate the two, but in this case adequate data was not available to do so. Because the load is mostly attributable to base-flow concentrations, it is difficult to determine the specific sources. The point source and nonpoint source allocations for BOD are summarized in Table 2. Appendix A provides more detailed computations of these loads.

Table 2: Point source and nonpoint source Load Allocations (lb/month)

	Nonpoint Source	**Point Source**
BOD	**1,040**	**75,080**

The nonpoint source load allocations were calculated for the 7Q10 flow. This produced a very small load allocation for nonpoint sources. It must be made clear that the above load allocations assume no runoff loads due to rainfall. Scenario 2 showed that when the flows in the river were increased and the NPDES stormwater permitted yardwaste composting facility was discharging maximum flows and loads, there were no water quality violations within the modeling domain. Figure 13, located at the end of the *Modeling Results* section, showed that when the river flows were increased and the point and nonpoint source concentrations remained unchanged, the water quality in the river was maintained. The assumption of constant concentrations was an approximation made to double check that the 7Q10 allocations would not violate water quality standards at higher flows. To allocate loads at higher flows a more detailed analysis of the instream concentrations of water quality constituents would have to be performed. This document only allocates loads during 7Q10 conditions. The nonpoint source load allocations may increase above those stated in the TMDL for flows higher than the 7Q10 flow.

Future Allocations and Margin of Safety

Future allocations represent surplus assimilative loading capacity that is either currently available, or projected to become available due to planned implementation of environmental controls or other changes. The water quality monitoring station WXT0045 marks the upper boundary of the modeling domain. The current BOD concentration at this upper boundary is estimated to be 2.0 mg/l. Additional future BOD loads to the upper portion of the Western Branch watershed, above station WXT0045, are allowable provided they do not cause a localized impairment. It was determined that 9.0 additional mg/l could be introduced at the upper boundary of the model, and the in-stream water quality would still be met at all locations in the modeling domain. It was also determined that 9.0 additional mg/l of BOD could be introduced from the Charles Branch. The future allocation for BOD can be seen in Table 3.

As with the load allocation, the future allocation will also increase as the flows rise above the 7Q10 flow. To allocate loads at higher flows a more detailed analysis of the instream concentrations would have to be performed. This document only allocates a load during 7Q10 conditions. The future allocation may increase above that stated in the TMDL for flows higher than the 7Q10 flow.

The TMDL must include a margin of safety (MOS) in recognition of the uncertainties in our scientific and technical understanding of water quality in natural systems. Specifically, we cannot know the exact nature and magnitude of pollutant loads from various sources and the specific impacts of those pollutants on the chemical and biological quality of complex natural waterbodies. The MOS is intended to account for such uncertainties in a manner that is conservative from the standpoint of protection of the environment. Based on EPA guidance, the MOS can be achieved through one of two approaches: (1) reserve a portion of the loading capacity as a separate term in the TMDL, or (2) incorporate the MOS as part of the design conditions for the waste load allocations (WLA) and the load allocations (LA) computations (EPA, April 1991).

The TMDL for BOD in the Western Branch employs both of these approaches. In the TMDL, 4,040 lb/mo. of loading capacity was set aside as a margin of safety. The seventh model scenario incorporated the BOD MOSs at both the upper boundary of the model, at the Charles Branch Boundary, at the Western Branch WWTP, and at the Croom Manor WWTP. The MOS at the upper boundary of the model and at the Charles Branch boundary was 5% of the total load allocation plus future allocation. The MOS at both the Western Branch WWTP and the Croom Manor WWTP was calculated as 10 % of the difference between the weekly and monthly effluent permit limits. This was considered an appropriate MOS because is it is unlikely that either WWTP will go above their monthly limit more than a tenth of the time during a month.

In addition to the set-aside MOS, the design conditions for the WLA and the LA computations include two implicit MOSs. First, the critical condition of the consecutive 7-day low-flow expected to occur every 10 years was used to determine the final TMDL load allocations. Because the 7Q10 flow constitutes a worst case scenario, its use builds a conservative assumption into the TMDL. Second, all the modeling was done using the NPDES monthly permit limits for all effluent concentrations. The monthly limits are conservative because they represent an upper limit which the WWTPs will strive not to exceed to avoid paying a fine. The future allocations and MOS can be seen in Table 3.

Table 3: Future Allocation and Margin of Safety (lb/month)

	Future Allocation	Margin of Safety
BOD	**4,680**	**4,040**

Summary of Total Maximum Daily Load

The low-flow BOD TMDL for the Western Branch is (lb/month)[2]:

TMDL	=	LA	+	WLA	+	FA	+	MOS
84,840	**=**	**1,040**	**+**	**75,080**	**+**	**4,680**	**+**	**4,040**

Where:

LA = Load Allocation or Nonpoint Source
WLA = Waste Load Allocation or Point Source
FA = Future Allocation
MOS = Margin of Safety

Average Daily Loads

On average, this TMDL will result in a load of approximately 2,828 lb/day.

2 This BOD TMDL is based on the assumption that the Western Branch WWTP will continue to meet its current NPDES discharge limits for nitrogen, ammonia, and phosphorus, and that the Croom Manor WWTP will continue to meet its NPDES limit for nitrogen. In addition, this TMDL indicates that water quality standards will be met if dissolved oxygen concentrations from the Western Branch WWTP are increased to 7 mg/l. Specific NPDES permit limits for the Western Branch WWTP and the Croom Manor WWTP will be determined in the context of the NPDES permit renewal process.

ASSURANCE OF IMPLEMENTATION

This section provides the basis for reasonable assurances that the BOD TMDL will be achieved and maintained. Enforceable NPDES permits written for the WWTPs in this basin provide confidence in assuring implementation of this TMDL. Also, Maryland has recently adopted a five-year watershed cycling strategy to manage its waters. Pursuant to this strategy, the State is divided into five regions, and management activities will cycle through these regions over a five-year period. The cycle begins with intensive monitoring, followed by computer modeling, TMDL development, implementation activities, and follow-up evaluation. The choice of a five-year cycle is motivated by the five-year federal NPDES permit cycle. This continuing cycle ensures that, within five years of establishing a TMDL, intensive follow-up monitoring will be performed. Thus, the watershed cycling strategy establishes a TMDL evaluation process that assures accountability.

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APPENDIX A