C5.0 Total Maximum Daily Loads (TMDLs) Development Plan for Sub-basin #1 of West Branch Neshaminy Creek

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EXECUTIVE SUMMARY

West Branch Sub-basin #1 in Bucks County is approximately 2.5 square miles in size. West Branch Sub-basin #1 is a portion of the larger watershed surrounding West Branch Neshaminy Creek. The protected uses of the watershed are water supply, recreation, and aquatic life. Its aquatic use is warm water fishes and migratory fishes.

Total Maximum Daily Loads (TMDLs) apply to about 3.5 miles of this West Branch Neshaminy Creek tributary (Stream Segments ID#s 980205-1330-GLW, 980205-1333-GLW, and 492). They were developed to address the impairments noted on Pennsylvania's 1996 and 2002 Clean Water act Section 303(d) Lists. The impairments are primarily caused by sediment loads and water/flow variability due to land development/urban runoff-storm sewers in the watershed, and by flow alterations and nutrients as a result of a municipal point source. The TMDL discussed in this section focuses on control of sediments. Nutrients from the sole municipal point source in the sub-basin are discussed separately in Section D. Water/flow variability and flow alterations were not explicitly addressed because it was believed that the implementation of various BMPs in this highly urbanized watershed to reduce sediment would also decrease peak water volumes to the stream, and therefore stabilize stream flow.

Pennsylvania does not currently have water quality criteria for sediment. For this reason, a modeling approach was developed to identify the TMDL endpoints or water quality objectives for sediment in the impaired segments of West Branch Sub-basin #1. This approach is based on the comparison of simulated sediment loads at two time periods: Year 1992 when the stream was still attaining and Year 2000 when it was found to be impaired. Siltation, the cause of impairment in West Branch Sub-basin #1, resulted from the accumulation of sediments originating from construction and newly developed land over several years. It was estimated that the sediment loading that will meet the water quality objectives for West Branch Sub-basin #1 is 143,267 pounds per year. It is also assumed that West Branch Sub-basin #1 will support its aquatic life uses when this value is met. The sediment TMDL for West Branch Sub-basin #1 is allocated as shown in the table below.

Summary of TMDLs for West Branch Sub-basin #1 Watershed (lbs/yr)

Pollutant	Source	TMDL	MOS	WLA	LA	LNR	ALA
Sediment	Upland and stream bank erosion	143,267	14,327	128,940	-	-	-

The TMDL for sediment is allocated to all non-point sources of upland and stream bank erosion, with 10% of the TMDL total load reserved as a margin of safety (MOS). In this case, all sediment loads were assigned to the waste load allocation (WLA) category. The sediment TMDL covers a total of 3.5 miles of streams in this sub-watershed. The TMDL establishes a reduction for total sediment loading of 16% from the current annual loading of 154,296 pounds, which also factors in the 10% MOS.

C5.0 INTRODUCTION

C5.0.1 Watershed Description

The following discussion provides information on the physical characteristics of West Branch Sub-basin #1, including location, land use distributions, and geology. West Branch Sub-basin #1 is located in the Piedmont physiographic province and is in Montgomery County. It covers an area of approximately 2.5 square miles. West Branch Sub-basin #1 drains into the West Branch of Neshaminy Creek from the west. The watershed is located northeast of the town of Lansdale, and is bounded by Pennsylvania Route 463 to the north and east and Route 63 to the west. Figure C5.1 shows the watershed boundary, its location, and water quality status of stream segments as reported on the 2002 303(d) List. The designated uses of the watershed include water supply, recreation and aquatic life. As listed in the Title 25 PA Code Department of Environmental Protection Chapter 93, Section 93.o (Commonwealth of PA, 1999), the designated aquatic life use for the West Branch Sub-basin #1and is warm water fishes and migratory fishes.

The current land use distribution in West Branch Sub-basin #1 was developed by updating the National Land Cover Data (NLCD) layer described by Vogelmann et al. (1998) using a recent 10-m colorized panchromatic SPOT (System Probatoire pour l'Observation de la Terre) satellite image. The NLCD layer was based primarily on 1992 Landsat Thematic Mapper (TM). SPOT imagery was acquired in 2000 and is available for the entire Commonwealth of Pennsylvania at the Pennsylvania Spatial Data Access (PASDA) site (http://spot.pasda.psu.edu) at no charge. The primary land use in West Branch Sub-basin #1 is developed land (about 79%). It is important to note that development in the watershed increased by about 3% from 1992 to 2000.

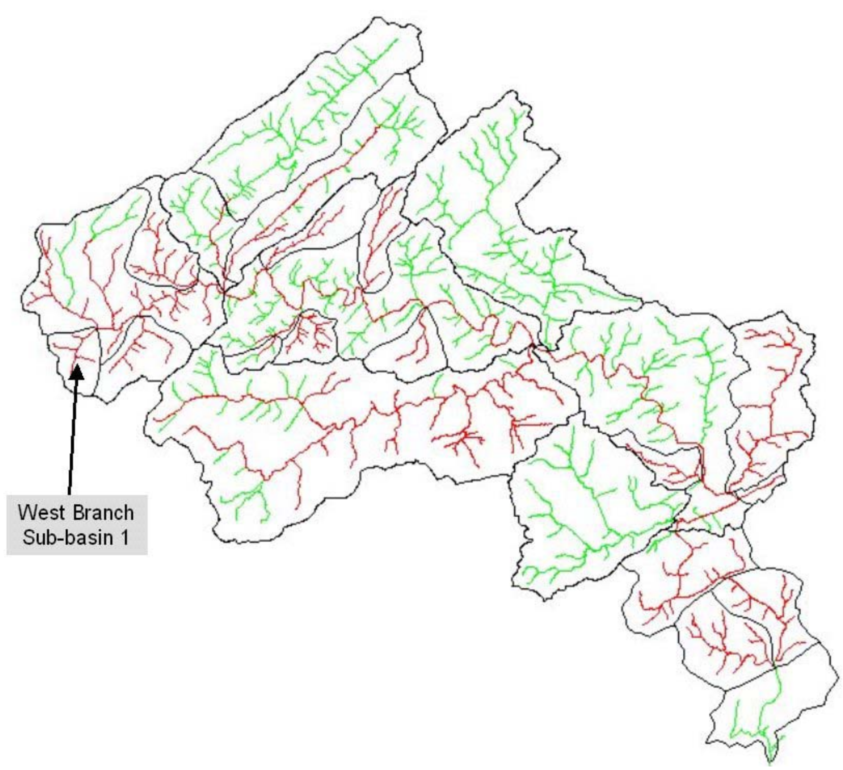

Figure C5.1. West Branch Sub-basin #1.

West Branch Sub-basin #1 is underlain by a shale formation. The bedrock geology primarily affects surface runoff and background nutrient loads through its influences on soils and landscape as well as fracture density and directional permeability. Soils are mostly sandy and very erodible, as indicated by a high average K factor (0.37). Watershed characteristics are summarized in Table C5.1.

Table C5.1. Physical characteristics of West Branch Sub-basin #1.

Attribute	***West Branch Sub-Basin #1***
Physiographic Province	Piedmont
Area (square miles)	2.5
Predominant Land Uses	-Developed land (79%) -Agricultural land (6%) -Forested land (17%)
Predominant Geology	Shale
Soils - Dominant HSG	C
- K Factor	0.37
20-Year Average Rainfall (in)	41.6
20-Year Average Runoff (in)	7.03

C5.0.2 Surface Water Quality

A Total Maximum Daily Load, or TMDL, was developed for West Branch Sub-basin #1 to address the impairments noted on Pennsylvania's 1996 and 2002 Clean Water Act Section 303(d) Lists (see Table A1 in section A1.0). It was first determined that West Branch Sub-basin #1 was not meeting its designated water quality uses for protection of aquatic life based on a 1994 aquatic biological survey, which included kick screen analysis and habitat surveys. In 2001, the Department surveyed the stream again. In addition to impairments observed in 1994, one stream segment was found to be impaired by siltation and water flow variability. As a consequence of the surveys, Pennsylvania listed streams in West Branch Sub-basin #1 on the 1996 and 2002 Section 303(d) Lists of Impaired Waters.

The 1996 list included 0.1 miles as being impaired by nutrients from a municipal point source. This impairment is discussed separately in Section D of this document. The 2002 list reported a total of 3.4 miles of West Branch Sub-basin #1 streams to be impaired by flow alterations from municipal point sources, and by siltation and water/flow variability as a result of urban runoff/storm sewers and land development.

Stream segments of West Branch Sub-basin #1 are impacted by siltation as a result of "new land development" in the watershed. New land development is defined here as disturbed land at construction sites/new development. It appeared from our reconnaissance surveys and contacts in the watershed that siltation presently observed in West Branch Sub-basin #1 is the result of years of sediment build-up in the channel bottom that started in the early 1990's. These sediments originated from disturbed and unprotected soils at construction sites and increased channel bank erosion during periods of intense storm events. As indicated above, land development has increased by approximately 3% between 1992 and 2000.

Sediments, which are often the cause of stream impairment in urban and suburban areas, are primarily from two sources: 1) disturbed land and unprotected soils at construction sites, and 2) stream channel erosion. Transitional land uses, mainly new construction sites, are one of the main sources of sediments in streams draining newly developed areas. Sediment production and sedimentation in streams are typically more important during the construction phase because soils are disturbed and exposed to detachment by raindrops and transported during storm events. Construction also renders landscapes unstable and cause soil to move in "sheets" and localized landslides during storm events.

Channel erosion and scour that occur in waterways and receiving waters located in urban and suburban areas may also be an important source of sediments. Channel erosion is primarily the result of elevated storm water runoff during storm events caused by increased impervious surfaces from residential, commercial and industrial areas; construction sites; roads; highways; and bridges in the watershed (Horner, 1990). Basically, impervious areas and disturbed land restrict water infiltration thus converting more rainfall into runoff during storm events. The visible impact of elevated storm runoff includes fallen trees, eroded and exposed stream banks, siltation, floating litter and debris, and turbid conditions in streams. All these events were observed during a reconnaissance survey of West Branch Sub-basin #1. In conclusion, addressing storm water runoff and sediment production at new construction sites through the use of management practices will assure that aquatic life use is achieved and maintained in West Branch Sub-basin #1. Without effective storm water management practices and sediment traps, build-up of sediments will continue to occur in the stream.

C5.1 APPROACH TO TMDL DEVELOPMENT

The present TMDL addresses impairment by sediment and nutrients in West Branch Sub-basin #1 stream segments as reported on the 2002 303(d) List. The flow alteration and water flow/variability impairments caused by municipal point sources and urban runoff/storm sewer were not explicitly addressed by this TMDL because it is assumed that management practices that will be used to address storm water runoff and sediment production at both developed and developing areas will reduce problems associated with flow variability as well. This TMDL was derived as follows:

C5.1.1 Water/Flow Variability from Land Development

A TMDL was not determined for water/flow variability. It was assumed that addressing sediment loads through the use of urban BMPs will at the same time reduce water flow variability within the watershed.

C5.1.2 Flow Alterations and Nutrients from Municipal Point Sources

A TMDL was not determined for flow alterations. It was assumed that addressing sediment loads through the use of urban BMPs will at the same time reduce water flow alterations within the watershed. The nutrient impairment is discussed separately in Section D.

C5.1.3 Siltation Caused by Urban Runoff/Storm Sewers

The 2001 survey showed that sediments caused by newly developed land in the watershed were the cause of impairment of West Branch Sub-basin #1 stream segments. Sediments deposited in large quantities on the streambed were degrading the habitat of bottom-dwelling macro-invertebrates. The TMDL for West Branch Sub-basin #1 addresses sediments from construction sites or “Transitional” land uses, and from stream bank erosion. Because neither Pennsylvania nor EPA has water quality criteria for sediments, we had to develop a method to determine water quality objectives for this parameter that would result in the impaired stream segments attaining their designated uses. The approach consists of:

> Comparing simulated annual sediment loads for Year 1992 and Year 2000 land use conditions in the watershed. It appeared from several field visits in the watershed that most of the siltation and turbidity observed in the stream have accumulated during several years. This assumption is supported by the fact that siltation was not found as a cause of impairment during the 1994 survey and 1997 assessments. Year 1992 is considered here as the benchmark because (as indicated earlier) the analysis of classified satellite images showed that development in the watershed increased by about 3% between 1992 and 2000.

C5.1.4 Nutrient Impairment due to Municipal Point Source

As indicated earlier, a stream segment within West Branch Sub-basin #1 (ID# 492) was listed as being impaired due to problems associated with nutrients from a municipal point source (PA0026182). Due to the different modeling approach used for point source problems in the Neshaminy Creek watershed, this stream impairment is not discussed here; rather, it is addressed separately in Section D2.3.1.

C5.1.5 Watershed Assessment and Modeling

The AVGWLF model was run for West Branch Sub-basin #1 to establish sediment loadings under differing land use/cover conditions (see section B for model-specific details). First, the model was run using the 1992 land use distributions provided by the National Land Cover Data (NLCD) set. As indicated earlier, NLCD land uses were developed by the MRLC Consortium using 1992-vintage Landsat TM imagery. Second, the model was performed for the Year 2000 land use conditions using an updated version of this earlier land use data set. SPOT imagery that was acquired in the summer of 2000 was used for the land use update. In this model, land in transition (transitional land use) was considered to be new development (built after 1992) or construction sites. Based on the use of 20 years of historical weather data, the mean annual loads for sediment for the 1992 and 2000 land use/ cover conditions were calculated as shown Tables

C5.2 and C5.3, respectively. The unit area load for sediment in the watershed was estimated by dividing the mean annual loading (lbs/yr) by the total area (acres) resulting in an approximate loading per unit area for the watershed. Table C5.4 presents an explanation of the header information contained in Tables C5.2 and C5.3 (as well as Tables C5.5 and C5.6 described later). Modeling output for West Branch Sub-basin #1 for 1992 and 2000 land use conditions is presented in Appendix F.

Table C5.2. Loading Values for West Branch Sub-basin #1, Year 1992 Land Use Conditions

Land Use Category	*Area (acres)*	*Sediment Load (lbs/year)*	*Unit Area Sediment Load (lbs/acre/yr)*
Hay/Pasture	32	728	22.75
Cropland	64	12,693	198.33
Coniferous Forest	10	0	0
Mixed Forest	101	221	2.19
Deciduous Forest	150	309	2.06
Transition	0	0	0
Low Intensity Dev	773	38,389	49.66
High Intensity Dev	430	19,316	44.92
Stream Bank		71,523	
Groundwater			
Point Source			
Septic Systems			
Total	1,560	143,267	91.84

Table C5.3. Loading Values for West Branch Sub-basin #1, Year 2000 Land Use Conditions

Land Use Category	*Area (acres)*	*Sediment Load (lbs/year)*	*Unit Area Sediment Load (lbs/acre/yr)*
Hay/Past	32	728	22.75
Cropland	64	12,693	198.33
Coniferous Forest	10	0	0
Mixed Forest	101	221	2.19
Deciduous Forest	104	199	1.91
Transitional	9	8,631	959.0
Low Intensity Dev	784	38,933	49.66
High Intensity Dev	456	20,484	44.92
Stream Bank		72,407	
Groundwater			
Point Source			
Septic Systems			
Total	1,560	154,296	98.91

Table C5.4. Header Information for Tables C5.2 and C5.3.	
Land Use Category	The land cover classification that was obtained by from the MRLC database
Area (acres)	The area of the specific land cover/land use category found in the watershed.
Sediment Load	The estimated total sediment loading that reaches the outlet point of the watershed that is being modeled. Expressed in lbs./year.
Unit Area Sediment Load	The estimated loading rate for sediment for a specific land cover/land use category. Loading rate is expressed in lbs/acre/year

C5.2 LOAD ALLOCATION PROCEDURE FOR SEDIMENT TMDL

The load allocation and reduction procedures were applied to the entire West Branch Sub-basin #1. For the sediment TMDL, the load reduction calculations were based on sediment loads that were obtained using 1992 land use conditions. This assumes that the watershed was attaining its designated uses prior to 1992. As indicated earlier, land development, which is the principal source of stream impairment in the watershed, has increased considerably since 1992. These "pre-development" loads were then used as the basis for establishing the TMDL for West Branch Sub-basin #1.

The basic equation defining the TMDL for sediment is as follows:

$$TMDL = MOS + LA + WLA \qquad (1)$$

TMDL is the TMDL total load. The LA (load allocation) is the portion of Equation (1) that is typically assigned to non-point sources. The MOS (margin of safety) is the portion of loading that is reserved to account for any uncertainty in the data and computational methodology used for the analysis. The WLA (Waste Load Allocation) is the portion of this equation that is typically assigned to point sources. However, as described below, this category was used to reflect sediment loads from all sources in this particular watershed. This was done for two primary reasons: 1) because "urban runoff/storm sewers" was listed as the primary source of sediment to impaired streams in this watershed, and 2) to be consistent with EPA guidance on how to handle sediment loads in urbanized watersheds. Details of how specific components of the overall TMDL calculation were derived are presented below.

C5.2.1 TMDL Total Load

As noted earlier, the TMDL total target loads for sediment in West Branch Sub-basin #1 is based on the sediment loads obtained using the 1992 land use conditions, and is equal to 143,267 lbs/year (see Table C5.2).

C5.2.2 Margin of Safety

The Margin of Safety (MOS) for this analysis is explicit. Ten percent of the TMDL was reserved as the MOS.

MOS (Sediments) *143,267 lbs/yr x 0.1 = 14,327 lbs/yr* *(2)*

C5.2.3 Waste Load Allocation for Sediment

For the purposes of this TMDL assessment, sediment loads from all sources have been assigned to the waste load allocation (WLA) category to be consistent with EPA guidance on how to handle sediment loads in urbanized watersheds. Therefore, the load allocation (LA) in this case is equal to zero. Allowing for an explicit 10% MOS, the target WLA is re-computed as:

WLA (Sediment) *143,267 lbs/yr – 14,327 lbs/yr = 128,940 lbs/yr* *(3)*

Tables that can be used to cross-reference sub-areas with municipalities in the Neshaminy Creek basin, as well as a summary of sediment-related WLAs, can be found in Appendix E. A map showing the overlap between sub-basin and municipal boundaries within the entire Neshaminy Creek basin is also included in this same appendix.

C5.2.4 Sediment Load Reduction Procedures

The allocation of sediment among contributing sources in West Branch Sub-basin #1 was done by reducing each source equally on a percentage basis. Based on the target WLA of 128,940 lbs/year described above, the computed load allocations are shown in Table C5.5.

The total allowable sediment load in West Branch Sub-basin #1 when all sources are considered is 128,940 pounds per year. In order for sediment-impaired stream segments to attain their specific uses, total sediment load should be reduced from the current load of 154,296 pounds per year by a factor of 16%.

C5.3 CONSIDERATION OF CRITICAL CONDITIONS

The AVGWLF model is a continuous simulation model, which uses daily time steps for weather data and water balance calculations. Monthly calculations are made for sediment and nutrient loads, based on the daily water balance accumulated to monthly values. Therefore, all flow conditions are taken into account for loading calculations. Because there is generally a significant lag time between the introduction of sediment and nutrients to a waterbody and the resulting impact on beneficial uses, establishing these TMDLs using average annual conditions is protective of the waterbody.

Table C5.5 Sediment Load Allocation by Each Land Use/Source					
Land Use Category	*Area (acres)*	*1992 Load (lbs/year)*	*2000 Load (lbs/year)*	*WLA (lbs/year)*	*Reduction (%)*
Hay/Pasture	32	728	728	608	16
Cropland	64	12,693	12,693	10,607	16
Coniferous Forest	10	0	0	0	-
Mixed Forest	101	221	221	184	16
Deciduous Forest	104	309	199	166	16
Transitional land	9	0	8,631	7,212	16
Low Intensity Devel	784	38,389	38,933	32,536	16
High Intensity Devel	456	19,316	20,484	17,118	16
Stream Bank Erosion		71,523	72,407	60,509	16
Groundwater					
Point Source					
Septic Systems					
Total	1,560	143,267	154,296	128,940	16

C5.4 CONSIDERATION OF SEASONAL VARIATIONS

The continuous simulation model used for this analysis considers seasonal variation through a number of mechanisms. Daily time steps are used for weather data and water balance calculations. The model requires specification of the growing season, and hours of daylight for each month. The model also considers the months of the year when manure is applied to the land. The combination of these actions by the model accounts for seasonal variability.

C5.6 REASONABLE ASSURANCE OF IMPLEMENTATION

Sediment reductions in the TMDL are allocated to sorces of upland and stream bank erosion in the watershed. Implementation of best urban best management practices (BMPs) in the affected areas to increase infiltration and sediment control measures should help achieve needed load reductions established in the TMDL. Substantial reductions in the amount of sediment reaching the streams can be made through the installation of drainage controls such as detention ponds, sediment ponds, infiltration pits, dikes and ditches. These BMPs range in efficiency from **20% to 70%** for sediment reduction. The implementation of such BMPs will likely occur in the watershed as a result of PaDEP's Proposed Comprehensive Stormwater Management Policy. When approved, this new policy will require affected communities to implement BMPs to address stormwater control that will "reduce pollutant loadings to streams, recharge groundwater tables, enhance stream base flow during times of drought and reduce the threat of flooding and stream bank erosion resulting from storm events." Over the next year and one-half, PaDEP will be developing a "Phase II" program for NPDES discharges from small construction sites, additional industrial activities, and for the 700 municipalities subject to the requirements for separate storm sewer systems (MS4). All of the municipalities located within West Branch Sub-basin #1 will be affected by this policy, which has been included in Appendix E. Tables that can be used to cross-reference sub-areas with municipalities in the Neshaminy Creek basin, as well as a summary of sediment-related WLAs, can be found in Appendix E. A map showing the overlap between sub-basin and municipal boundaries within the entire Neshaminy Creek basin is also included in this same appendix. Implementation of BMPs aimed at reducing sediment loads in the watershed will also assist in the reduction of phosphorus originating from developing areas and stream bank erosion.

C5.7 PUBLIC PARTICIPATION

Notice of the draft TMDL will be published in the *PA Bulletin* and local newspapers with a 30-day comment period provided. A public meeting with watershed residents will be held to discuss the TMDL. Notice of final TMDL approval will be posted on the Department website.

C6.0 Total Maximum Daily Loads (TMDLs) Development Plan for West Branch Neshaminy Creek Sub-basin #2

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EXECUTIVE SUMMARY

Sub-basin #2 of West Branch Neshaminy Creek is approximately 4 square miles in size. The protected uses of the watershed are water supply, recreation, and aquatic life. Its aquatic use is warm water fishes and migratory fishes.

Total Maximum Daily Loads (TMDLs) apply to about 4.9 miles of this sub-basin (Stream Segment ID# 980202-1441-GLW). They were developed to address the impairments noted on Pennsylvania's 2002 Clean Water Act Section 303(d) List. The impairments are primarily caused by sediment loads from land development in the watershed. The TMDL, therefore, focuses on control of sediments. This stream segment was also listed as being impaired by water/flow variability due to urban runoff/storm sewers. Water/flow variability was not explicitly addressed because it was believed that the implementation of BMPs to reduce sediment in this urbanized sub-watershed would also decrease water flow and volume to the stream and therefore stabilize stream flow.

Pennsylvania does not currently have water quality criteria for sediment. For this reason, a modeling approach was developed to identify the TMDL endpoints or water quality objectives for sediment in the impaired segments of West Branch Sub-basin #2. The approach is based on the comparison of simulated sediment loads at two time periods: Year 1992 when the stream was still attaining and Year 2000 when it was found to be impaired. Siltation, the cause of impairment in West Branch Sub-basin #2, resulted from the accumulation of sediments originating from construction and newly developed land over several years. It was estimated that the sediment loading that will meet the water quality objectives for West Branch Sub-basin #2 is 328,477 pounds per year. It is assumed that the West Branch Sub-basin #2 will support its aquatic life uses when this value is met. The sediment TMDL for West Branch Sub-basin #2 is allocated as shown in the table below.

Summary of TMDL for West Branch Sub-basin #2 (lbs/yr)							
Pollutant	**Source**	**TMDL**	**MOS**	**WLA**	**LA**	**LNR**	**ALA**
Sediment	Upland and stream bank erosion	328,477	32,848	295,629	-	-	-

The TMDL for sediment is allocated to all non-point sources of upland and stream bank erosion, with 10% of the TMDL total load reserved as a margin of safety (MOS). In this case, all sediment loads were assigned to the waste load allocation (WLA) category. The sediment TMDL covers a total of 4.9 miles of stream in the sub-watershed. The TMDL establishes a reduction for total sediment loading of 56% from the current annual loading of 682,119 pounds, which also accounts for the 10% MOS.

C6.0 INTRODUCTION

C6.0.1 Watershed Description

The following discussion provides information on the physical characteristics of West Branch Sub-basin #2, including its location, land use distributions, and geology. West Branch Sub-basin #2 is located in the Piedmont physiographic province and is almost entirely located in Montgomery County. It covers an area of approximately 4 square miles. West Branch Sub-basin #2 drains into the West Branch of Neshaminy Creek from the west. The watershed is located east of the town of Lansdale and is bounded by Pennsylvania Route 463 to the north and east and Route 63 to the west. Figure C6.1 shows the watershed boundary, its location, and water quality status of stream segments as reported on the 2002 303(d) List. The designated uses of the watershed include water supply, recreation and aquatic life. As listed in the Title 25 PA Code Department of Environmental Protection Chapter 93, Section 93.o (Commonwealth of PA, 1999), the designated aquatic life use for the West Branch Sub-basin #2 is warm water fishes and migratory fishes.

The current land use distribution in West Branch Sub-basin #2 was developed by updating the National Land Cover Data (NLCD) layer described by Vogelmann et al. (1998) using a recent 10-m colorized panchromatic SPOT (System Probatoire pour l'Observation de la Terre) satellite image. The NLCD layer was based primarily on 1992-vintage Landsat Thematic Mapper (TM) imagery. SPOT imagery was acquired in 2000 and is available for the entire Commonwealth of Pennsylvania at the Pennsylvania Spatial Data Access (PASDA) site (http://spot.pasda.psu.edu) at no charge. The primary land uses in West Branch Sub-basin #2 are developed land (63%) and forested land (29%). It is important to note that development in the watershed changed from 1353 to 1584 acres, or a 15% increase from 1992 to 2000.

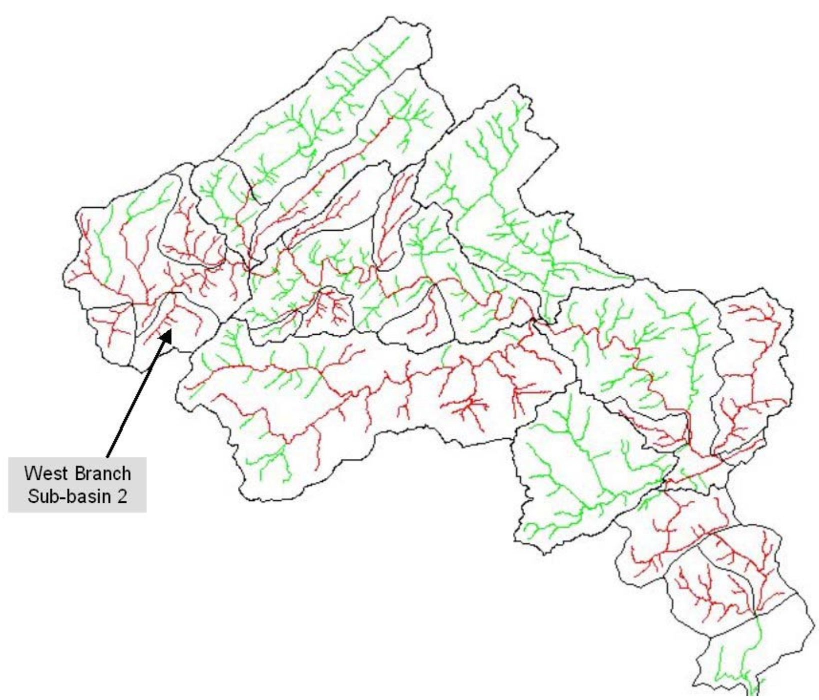

Figure C6.1. West Branch Sub-basin #2.

West Branch Sub-basin #2 is underlain by a shale formation. The bedrock geology affects primarily surface runoff and background nutrient loads through its influences on soils and landscape as well as fracture density and directional permeability. Soils are mostly sandy and very erodible, as indicated by a high average K factor (0.37). Watershed characteristics are summarized in Table C6.1.

C6.0.2 Surface Water Quality

Total Maximum Daily Loads, or TMDLs, were developed for West Branch Sub-basin #2 to address the impairments noted on Pennsylvania's 2002 Clean Water Act Section 303(d) List (see Table A1 in Section A1.0). It was first determined that stream reaches in West Branch Sub-basin #2 were not meeting their designated water quality uses for protection of aquatic life in 2001 based on an aquatic biological survey. As a consequence, streams in West Branch Sub-basin #2 were included on the 2002 Section 303(d) List of Impaired Waters.

Table C6.1. Physical Characteristics of West Branch Sub-basin #2.

Physiographic Province	Piedmont
Area (square miles)	4
Predominant Land Use	Developed land (63%) Forested land (29%)
Predominant Geology	Shale (100%)
Soils	
Dominant HSGs	C
Average K Factor	0.37
20-Year Average Rainfall (in)	40.4
20-Year Average Runoff (in)	5.4

The 2002 303 (d) List reported 4.9 miles of streams in West Branch Sub-basin #2 (Stream Segment ID# 980202-1441-GLW) to be impaired by siltation from land development and water/flow variability as a result of urban runoff/storm sewers. This particular stream reach is impacted by siltation as a result of "new land development" in the watershed. New land development is defined here as disturbed land at construction sites/new development. It appeared from our reconnaissance surveys and contacts in the watershed that siltation presently observed in West Branch Sub-basin #2 is the result of years of a build-up of sediments in the channel bottom that started in the early 1990's. These sediments originated from disturbed and unprotected soils at construction sites and increased channel bank erosion during periods of intense storm events. As indicated above, land development has increased by approximately 15% between 1992 and 2000.

Sediments, which are often the cause of stream impairment in urban and suburban areas, are primarily from two sources: 1) disturbed land and unprotected soils at construction sites, and 2) stream channel erosion. Transitional land uses, mainly new construction sites, are one of the main sources of sediments in streams draining newly developed areas. Sediment production and sedimentation in streams are typically most important during the construction phase because soils are disturbed and exposed to detachment by raindrops and transported during storm events. Construction also renders landscapes unstable and cause soil to move in "sheets" and localized landslides during storm events.

Channel erosion and scour that occur in waterways and receiving waters located in urban and suburban areas may also be an important source of sediments. Channel erosion is primarily the result of elevated storm water runoff during storm events caused by increased impervious surfaces from residential, commercial and industrial areas; construction sites; roads; highways; and bridges in the watershed (Horner, 1990). Basically, impervious areas and disturbed land restrict water infiltration thus converting more rainfall into runoff during storm events. The visible impact of elevated storm runoff includes fallen trees, eroded and exposed stream banks, siltation, floating litter and debris, and turbid conditions in streams. All of these conditions were observed during a reconnaissance survey of West Branch Sub-basin #2. In conclusion, addressing storm water runoff and sediment production at new construction sites through the use of management practices will assure that aquatic life use is achieved and maintained in West Branch Sub-basin #2. Without effective storm water management practices and sediment traps, build-up of sediments will continue to occur in the stream.

C6.1 APPROACH TO TMDL DEVELOPMENT

The present TMDL addresses impairment by sediment in West Branch Sub-basin #2 stream segments as reported on the 2002 303(d) Lists. The stream water flow variability impairment caused by urban runoff/storm sewer will not be explicitly addressed by this TMDL because it is assumed that management practices that will be used to address storm water runoff and sediment production in developed and developing areas will reduce problems associated with flow variability as well. This TMDL was derived as follows:

C6.1.1 Water/Flow Variability Resulting from Urban Runoff/Storm Sewers

A TMDL was not determined for water/flow variability. It was assumed that addressing sediment loads through the use of various BMPs in this highly urbanized watershed will at the same time reduce water flow variability within the watershed.

C6.1.2 Siltation Caused by Urban Runoff/Storm Sewers

The 2001 survey showed that sediments originating from newly developed land in the watershed were the cause of impairment of West Branch Sub-basin #2 stream segments. Sediments deposited in large quantities on the streambed were degrading the habitat of bottom-dwelling macro-invertebrates. The TMDL for West Branch Sub-basin #2 addresses sediment from construction sites or "Transitional" land uses, and from stream bank erosion. Because neither Pennsylvania nor EPA has water quality criteria for sediments, we had to develop a method to determine water quality objectives for this parameter that would result in the impaired stream segments attaining their designated uses. The approach consists of:

> Comparing simulated annual sediment loads for Year 1992 and Year 2000 land use conditions in the watershed. It appeared from several field visits in the watershed that most of the siltation and turbidity observed in the stream have accumulated during several years. This assumption is supported by the fact that siltation was not found as a cause of impairment during the 1994 survey and 1997 assessments. Year 1992 is considered here as the benchmark because (as indicated earlier) the analysis of classified satellite images showed that development in the watershed increased by about 15% between 1992 and 2000.

C6.1.3 Watershed Assessment and Modeling

The AVGWLF model was run for West Branch Sub-basin # 2 to establish sediment loadings under differing land use/cover conditions (see section B for model-specific details). First, the model was run using the 1992 land use distributions provided by the National Land Cover Data (NLCD) set. As indicated earlier, NLCD land uses were developed by the MRLC Consortium using primarily 1992-vintage Landsat TM imagery. Second, the model was performed for the Year 2000 land use conditions using an updated version of this earlier land use data set. SPOT imagery that was acquired in the summer of 2000 was used for the land use update. In this model, land in transition (transitional land use) was considered to be new development (built after 1992) or construction sites.

Prior to running the model for the two land use conditions as described, historical stream water quality data for the period 4/89 to 3/96 were first used to calibrate various key parameters within the GWLF model. Such data sets are typically not available in AVGWLF-based TMDL assessments done elsewhere in Pennsylvania. In this case, however, it was felt that model calibration would provide for better simulation of localized watershed processes and conditions. A description of the calibration procedure used can be found in section B1.4 of this document.

Using the refined parameter estimates based on the calibration results, AVGWLF was re-run for West Branch Sub-basin #2. Based on the use of 20 years of historical weather data, the mean annual loads for sediment for the 1992 and 2000 land use/ cover conditions were calculated as shown in Tables C6.2 and C6.3, respectively. The Unit Area Load for sediment in the watershed was estimated by dividing the mean annual loading (lbs/yr) by the total area (acres) resulting in an approximate loading per unit area for the watershed. Table C6.4 presents an explanation of the header information contained in Tables C6.2 and C6.3. Modeling output for West Branch Sub-basin #2 for 1992 and 2000 land use conditions is presented in Appendix F.

Table C6.2. Loading Values for West Branch Sub-basin #2, Year 1992 Land Use Conditions			
Land Use Category	*Area (acres)*	*Sediment Load (lbs/year)*	*Unit Area Sediment Load (lbs/acre/yr)*
Hay/Pasture	104	3,929	37.78
Cropland	274	113,333	413.62
Coniferous Forest	57	154	2.70
Mixed Forest	163	487	2.98
Deciduous Forest	570	2,230	3.91
Transition	0	0	0
Low Intensity Dev	1,052	79,271	73.35
High Intensity Dev	301	14,481	48.11
Stream Bank		114,570	
Groundwater			
Point Source			
Septic Systems			
Total	2,521	328,477	130.30

Table C6.3. Loading Values for West Branch Sub-basin #2, Year 2000 Land Use Conditions			
Land Use Category	*Area (acres)*	*Sediment Load (lbs/year)*	*Unit Area Sediment Load (lbs/acre/yr)*
Hay/Pasture	89	3,091	34.73
Cropland	114	24,840	217.89
Coniferous Forest	54	154	2.86
Mixed Forest	163	487	2.99
Deciduous Forest	516	2,053	3.98
Transitional	187	425,717	2,276.56
Low Intensity Dev	1091	82,914	76.00
High Intensity Dev	306	15,475	50.57
Stream Bank		117,779	
Groundwater			
Point Source			
Septic Systems			
Total	2,521	672,510	266.76

Table C6.4. Header Information for Tables C6.2 and C6.3.	
Land Use Category	The land cover classification that was obtained by from the MRLC database
Area (acres)	The area of the specific land cover/land use category found in the watershed.
Total Sediment	The estimated total sediment loading that reaches the outlet point of the watershed that is being modeled. Expressed in lbs./year.
Unit Area Sediment Load	The estimated loading rate for sediment for a specific land cover/land use category. Loading rate is expressed in lbs/acre/year

C6.2 LOAD ALLOCATION PROCEDURE FOR SEDIMENT TMDL

The load allocation and reduction procedures were applied to the entire area within West Branch Sub-basin #2. The load reduction calculations are based on sediment loads that were obtained using 1992 land use conditions. This assumes that the watershed was attaining its designated uses prior to 1992. As indicated earlier, land development, which is the source of stream impairment in the watershed, has increased considerably since 1992. These loads were then used as the basis for establishing the TMDL for West Branch Sub-basin #2.

The basic equation defining the TMDL for sediment is as follows:

$$TMDL = MOS + LA + WLA \qquad (1)$$

TMDL is the TMDL total load. The LA (load allocation) is the portion of Equation (1) that is typically assigned to non-point sources. The MOS (margin of safety) is the portion of loading that is reserved to account for any uncertainty in the data and computational methodology used for the analysis. The WLA (Waste Load Allocation) is the portion of this equation that is typically assigned to point sources. However, as described below, this category was used to reflect sediment loads from all sources in this particular watershed. This was done for two primary reasons: 1) because "urban runoff/storm sewers" was listed as the primary source of sediment to impaired streams in this watershed, and 2) to be consistent with EPA guidance on how to handle sediment loads in urbanized watersheds. Details of how specific components of the overall TMDL calculation were derived are presented below.

C6.2.1 Sediment TMDL Total Load

As noted earlier, the TMDL total target load for West Branch Sub-basin #2 is based on the sediment loads obtained using the 1992 land use conditions, and are equal to 328,477 lbs/yr (see Table C6.2).

C6.2.2 Margin of Safety

The Margin of Safety (MOS) for this analysis is explicit. Ten percent of the TMDL was reserved as the MOS.

MOS (Sediments) *328,477 lbs/yr x 0.1 = 32,848 lbs/yr* *(2)*

C6.2.3 Waste Load Allocation

For the purpose of this TMDL assessment, sediment loads from all sources have been assigned to the waste load allocation (WLA) category to be consistent with EPA guidance on how to handle sediment loads in urbanized watersheds. Therefore, the load allocation (LA) in this case is equal to zero. Allowing for an explicit 10% MOS, the target WLA is re-computed as:

WLA (Sediments) *328,477 lbs/yr - 32,848 lbs/yr = 295,629 lbs/yr* *(3)*

Tables that can be used to cross-reference sub-areas with municipalities in the Neshaminy Creek basin, as well as a summary of sediment-related WLAs, can be found in Appendix E. A map showing the overlap between sub-basin and municipal boundaries within the entire Neshaminy Creek basin is also included in this same appendix.

C6.2.4 Load Reduction Procedures

The allocation of sediment among contributing sources in West Branch Sub-Basin #2 was done by reducing each source equally on a percentage basis. Based on the target WLA of 295,629 lbs/year described above, the computed load allocations are those shown in Table C6.5.

Table C6.5 Sediment Load Allocation by Each Land Use/Source

Land Use Category	*Area (acres)*	*1992 Load (lbs/year)*	*2000 Load (lbs/year)*	*WLA (lbs/year)*	*Reduction (%)*
Hay/Pasture	89	3,929	3,091	1,359	56
Cropland	114	113,333	24,840	10,920	56
Coniferous Forest	54	154	154	68	56
Mixed Forest	163	487	487	215	56
Deciduous Forest	516	2,230	2,053	903	56
Transitional land	187	0	425,717	187,140	56
Low Intensity Devel	1091	79,271	82,914	36,452	56
High Intensity Devel	306	14,481	15,475	6,802	56
Stream Bank Erosion		114,570	117,779	51,770	56
Groundwater					
Point Source					
Septic Systems					
Total	2,521	328,477	672,510	295,629	56

The total allowable sediment load in West Branch Sub-basin #2 when all sources are considered (as well as the 10% MOS) is 295,629 pounds per year. In order for all sediment-impaired stream segments to attain their specific uses, total sediment load should be reduced from the current load of 672,510 pounds per year by a factor of 56%.

C6.3 CONSIDERATION OF CRITICAL CONDITIONS

The AVGWLF model is a continuous simulation model, which uses daily time steps for weather data and water balance calculations. Monthly calculations are made for sediment and nutrient loads, based on the daily water balance accumulated to monthly values. Therefore, all flow conditions are taken into account for loading calculations. Because there is generally a significant lag time between the introduction of sediment and nutrients to a waterbody and the resulting impact on beneficial uses, establishing the TMDL using average annual conditions is protective of the waterbody.

C6.4 CONSIDERATION OF SEASONAL VARIATIONS

The continuous simulation model used for this analysis considers seasonal variation through a number of mechanisms. Daily time steps are used for weather data and water balance calculations. The model requires specification of the growing season, and hours of daylight for each month. The model also considers the months of the year when manure is applied to the land. The combination of these actions by the model accounts for seasonal variability.

C6.5 REASONABLE ASSURANCE OF IMPLEMENTATION

Sediment reductions in the TMDLs are allocated to all sources of upland and stream bank erosion in the watershed. Implementation of best urban best management practices (BMPs) in the affected areas to increase infiltration and sediment control measures should achieve the loading reduction goals established in the TMDLs. Substantial reductions in the amount of sediment reaching the streams can be made through the installation of drainage controls such as detention ponds, sediment ponds, infiltration pits, dikes and ditches. . These BMPs range in efficiency from **20% to 70%** for sediment reduction. The implementation of such BMPs will likely occur in the watershed as a result of PaDEP's Proposed Comprehensive Stormwater Management Policy. When approved, this new policy will require affected communities to implement BMPs to address stormwater control that will "reduce pollutant loadings to streams, recharge groundwater tables, enhance stream base flow during times of drought and reduce the threat of flooding and stream bank erosion resulting from storm events." Over the next year and one-half, PaDEP will be developing a "Phase II" program for NPDES discharges from small construction sites, additional industrial activities, and for the 700 municipalities subject to the requirements for separate storm sewer systems (MS4). All of the municipalities located within West Branch Sub-basin #2 will be affected by this policy, which has been included in Appendix E. Tables that can be used to cross-reference sub-areas with municipalities in the Neshaminy Creek basin, as well as a summary of sediment-related WLAs, can be found in Appendix E. A map showing the overlap between sub-basin and municipal boundaries within the entire Neshaminy Creek basin is also included in this same appendix. Implementation of BMPs aimed at sediment reduction will also assist in the reduction of phosphorus originating from transitional land uses and stream bank erosion.

C6.7 PUBLIC PARTICIPATION

Notice of the draft TMDL will be published in the *PA Bulletin* and local newspapers with a 30-day comment period provided. A public meeting with watershed residents will be held to discuss the TMDL. Notice of final TMDL approval will be posted on the Department website.

C7.0 Total Maximum Daily Loads (TMDLs) Development Plan for Sub-Basin #3 of West Branch Neshaminy Creek

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EXECUTIVE SUMMARY

West Branch Sub-basin #3 in Bucks County is approximately 4 square miles in size and is a tributary of West Branch Neshaminy Creek. The protected uses of the watershed are water supply, recreation, and aquatic life. Its aquatic use is warm water fishes and migratory fishes.

Total Maximum Daily Loads (TMDLs) apply to 8.5 miles of the streams within this particular sub-basin (Stream Segments ID# 980202-1313-GLW and 20010426-1235-GLW). They were developed to address the impairments noted on Pennsylvania's 1996 and 2002 Clean Water act Section 303(d) List. The impairments are primarily caused by nutrient and sediment loads from land development and agriculture in the watershed. The TMDL, therefore, focuses on control of nutrients and sediments. Phosphorus is generally considered to be the limiting nutrient in a water body when the nitrogen/phosphorus ratio exceeds 10 to 1. In West Branch Sub-basin #3, this ratio is 13 to 1.

Pennsylvania does not currently have water quality criteria for nutrients and sediments. For this reason, we developed a reference watershed approach to identify the TMDL endpoints or water quality objectives for nutrients and sediments in the impaired segments of the West Branch Sub-basin #3. Based upon comparison to a similar, non-impaired watershed, it was estimated that the amount of phosphorus loading that will meet the water quality objectives for West Branch Sub-basin #3 is 1,233 pounds per year. Sediment loading must be limited to 496,654 pounds per year. It is assumed that West Branch Sub-basin #3 will support its aquatic life uses when these values are met. The TMDLs for West Branch Sub-basin #3 are allocated as shown in the table below.

Summary of TMDL for West Branch Sub-basin #3 (lbs/yr)

Pollutant	TMDL	MOS	WLA	LA	LNR	ALA
Phosphorus	1,233	123	0	1,110	498	612
Sediment	496,654	49,665	446,989	-	-	-

The TMDLs are allocated to non-point source from agricultural and land development activities, with 10% of the TMDL total load reserved as a margin of safety (MOS). The TMDLs cover a total of 8.5 miles of streams in West Branch Sub-basin #3. The TMDL establishes a reduction for phosphorus loading from agricultural and land development activities of 23% from the current annual loading of 1,437 pounds, and a reduction in sediment loading of 52% from the current annual loading of 930,419 pounds. These reductions also account for the 10% MOS.

C7.0 INTRODUCTION

C7.0.1 Watershed Description

The following discussion provides information on the physical characteristics of West Branch Sub-basin #3 including its location, land use distributions, and geology. West Branch Sub-basin #3 is located in the Piedmont physiographic province and in Bucks County. It covers an area of approximately 4 square miles. The streams in West Branch Sub-basin #3 drain into the main stem of West Branch Neshaminy Creek from the north. The sub-basin is located east of the town of New Britain and is bounded by Pennsylvania Route 309 to the west, Route 152 to the east, and Route 202 to the south. Figure C7.1 shows the sub-basin boundary and its location. The designated uses of the watershed include water supply, recreation and aquatic life. As listed in the Title 25 PA Code Department of Environmental Protection Chapter 93, Section 93.o (Commonwealth of PA, 1999), the designated aquatic life use for the streams in West Branch Sub-basin #3 is warm water fishes and migratory fishes.

The primary land uses in West Branch Sub-basin #3 are agriculture (53%) and forested land (45%), with areas adjacent to the stream primarily used for cropland and pasture. It was found also from a field survey of the watershed that cattle generally have free access to the stream. The majority of the streams had no protected riparian zone. The 1994 survey showed that nutrients from agricultural activities were causing increased algae growth. It also found that sediment deposited in large quantities on the streambed was degrading the habitat of bottom-dwelling macroinvertebrates.

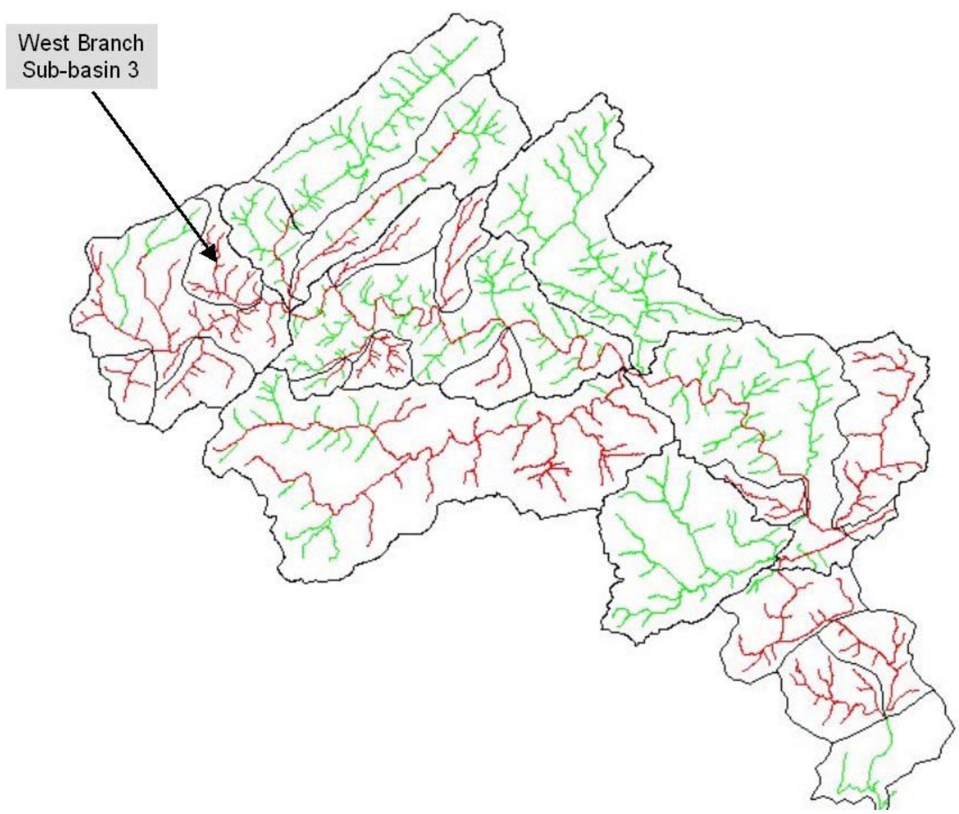

Figure C7.1. West Branch Sub-basin #3.

In terms of subsurface geology, West Branch Sub-basin #3 is primarily underlain by a shale formation. The bedrock geology affects primarily surface runoff and background nutrient loads through its influences on soils and landscape as well as fracture density and directional permeability. Soils are mostly sandy and very erodible, as indicated by a high average K factor (0.37). Characteristics of Sub-basin #3, as well as those of the reference watershed chosen for further analysis (see later discussion), are summarized in Table C7.1.

Table C7.1. Physical Characteristic Comparisons between West Branch Sub-basin #3 and Reference Watersheds

Attribute	West Branch Sub-basin #3	Reference Watershed
Physiographic Province	Piedmont	Piedmont
Area (square miles)	4	4
Predominant Land Uses	-Agriculture (53%) -Forested land (45%)	-Agriculture (47%) -Forested land (51%)
Predominant Geology	Shale (100%)	Shale (100%)
Soils - Dominant HSG	C	C
- K Factor	0.37	0.37
20-Year Average Rainfall (in)	40.4	41.0
20-Year Average Runoff (in)	3.8	3.8

C7.0.2 Surface Water Quality

Total Maximum Daily Loads or TMDLs were developed for West Branch Sub-basin #3 to address the impairments noted on Pennsylvania's 1996 and 2002 Clean Water Act Section 303(d) Lists (see Table A1 in section A1.0). It was first determined that West Branch Sub-basin #3 was not meeting its designated water quality uses for protection of aquatic life in 1994 based on aquatic biological survey. The 2001 survey found that that the stream was still impaired. As a consequence, Pennsylvania listed West Branch Sub-basin #3 on the 1996 and 2002 Section 303(d) List of Impaired Waters.

The 1996 303 (d) List reported 3.3 miles of West Branch Sub-basin #3 (Stream Segment ID# 980202-1313-GLW) to be impaired by siltation from construction and agriculture, and excessive algae growth as a result of agricultural activities in the watershed. The 2002 303 (d) List reported an additional 5.2 miles (Stream Segment ID# 210426-1235-GLW) to be impaired by siltation from agriculture and land development.

Sediments, which are often the cause of stream impairment in urban and suburban areas, are primarily from two sources: 1) disturbed land and unprotected soils at construction sites, and 2) stream channel erosion. Transitional land uses, mainly new construction sites, are one of the main sources of sediments in streams draining newly developed areas. Sediment production and sedimentation in streams are typically important during the construction phase because soils are disturbed and exposed to detachment by raindrops and transported during storm events. Construction also renders landscapes unstable and cause soil to move in "sheets" and localized landslides during storm events.

Channel erosion and scour that occur in waterways and receiving waters located in urban and suburban areas may also be an important source of sediments. Channel erosion is primarily the result of elevated storm water runoff during storm events caused by increased impervious surfaces from residential, commercial and industrial areas; construction sites; roads; highways; and bridges in the watershed (Horner, 1990). Basically, impervious areas and disturbed land restrict water infiltration thus converting more rainfall into runoff during storm events. The visible impact of elevated storm runoff includes fallen trees, eroded and exposed stream banks, siltation, floating litter and debris, and turbid conditions in streams. All these events were observed during a reconnaissance survey of West Branch Sub-basin #3. In conclusion, addressing storm water runoff and sediment production at new construction sites through the use of management practices will assure that aquatic life use is achieved and maintained in West Branch Sub-basin #3. Without effective storm water management practices and sediment traps, build-up of sediments will continue to occur in the stream.

C7.1 APPROACH TO TMDL DEVELOPMENT

C7.1.1 TMDL Endpoints

The TMDLs described herein address phosphorus and sediments. Phosphorus was determined to be the nutrient limiting plant growth in West Branch Sub-basin #3. Because neither Pennsylvania nor EPA has water quality criteria for phosphorus or sediments, we had to develop a method to determine water quality objectives for these parameters that would result in the impaired stream segments attaining their designated uses. The method employed for these TMDLs is termed the "reference watershed approach."

With the reference watershed approach, a pair of watersheds is compared; with one attaining its uses and one that is impaired based on biological assessment. Both watersheds must have similar land use/cover distributions. Other features such as base geologic formation should be matched to the greatest extent possible; however, most variations can be adjusted in the model. The objective of the process is to reduce the loading rate of nutrients and sediments in the watershed containing the impaired stream segment(s) to a level equivalent to or slightly lower than the loading rate in the watershed with the non-impaired, reference stream segment(s). The underlying assumption is that this load reduction will allow biological health to return to the impaired stream segments.

The TMDL endpoints established for this analysis were determined using a sub-watershed of the North Branch Neshaminy Creek watershed as the reference watershed. These endpoints are discussed in detail in the TMDL section. The listing for impairment caused by nutrients and siltation is addressed through reduction of both the phosphorus and sediment loads. A detailed explanation of this process is included in the following section.

C7.1.2 Selection of the Reference Watershed

In general, three factors should be considered when selecting a suitable reference watershed. The first factor is to use a watershed that has been assessed by the Department using the Unassessed Waters Protocol and has been determined to attain water quality standards. The second factor is to find a watershed that closely resembles the watershed being assessed (i.e., West Branch Sub-basin #3) with respect to physical properties such as land cover/land use, physiographic province, and geology. Finally, the size of the reference watershed should be within 20-30% of the impaired watershed area. The search for a reference watershed that would satisfy the above characteristics was done by means of desktop screening using several GIS coverages including the Multi-Resolution Land Characteristics (MRLC) Landsat-derived land cover/use grid, the Pennsylvania's 305(b) assessed streams database, and geologic rock types.

The watershed used as a reference for West Branch Sub-basin #3 was obtained by screen-digitizing a sub-watershed of the North Branch Neshaminy Creek watershed. This watershed is also located in the Piedmont province in State Water Plan (SWP) Basin 2F. Table C7.1 compares the two watersheds in terms of their size, location, and other physical characteristics. All reference watershed stream segments have been assessed and were found to be unimpaired. Figure C7.2 shows the reference watershed boundary and its location in Bucks County.

An analysis of the MRLC land use/cover layer revealed that land cover/use distributions in both watersheds are very similar. The surficial geology of both West Branch Sub-basin #3 and the reference watershed is shale. A look at these attributes in Table C7.1 indicates that these watersheds also compare very well in terms of average runoff, precipitation, and soil K factor.

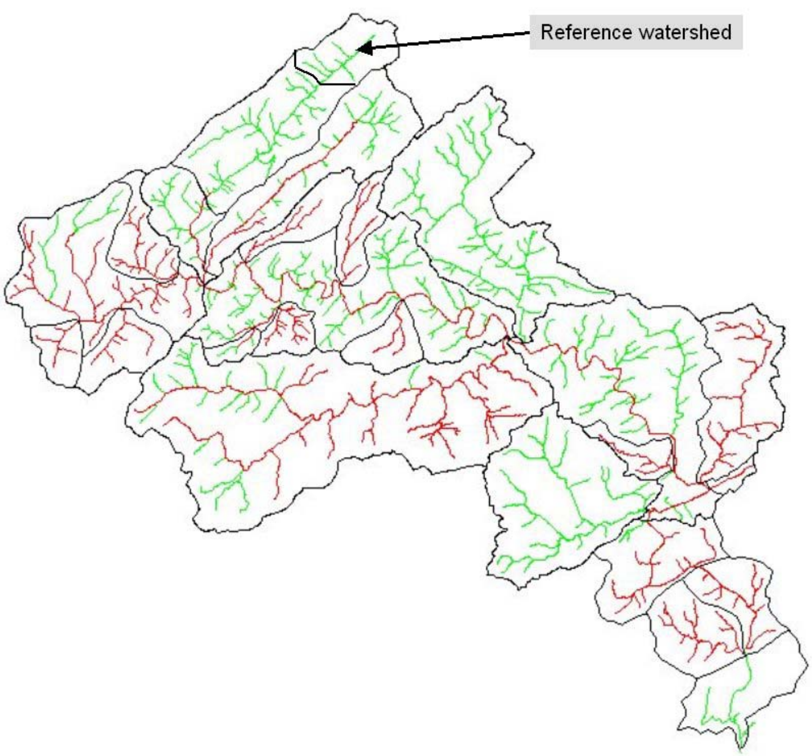

Figure C7.2. Reference Watershed Location.

C7.1.3 Nutrient Loads and Organic Enrichment in Stream Systems

As indicated earlier, West Branch Sub-basin #3 was listed as being impaired due to problems associated with excessive algal growth and siltation. In stream systems, elevated nutrient loads (nitrogen and phosphorus in particular) can lead to increased productivity of plants and other organisms (Novotny and Olem, 1994).

Typically in aquatic ecosystems the quantities of trace elements are plentiful; however, nitrogen and phosphorus may be in short supply. The nutrient that is in the shortest supply is called the *limiting nutrient* because its relative quantity affects the rate of production (growth) of aquatic biomass. If the nutrient load to a water body can be reduced, the available pool of nutrients that can be utilized by plants and other organisms will be reduced and, in general, the total biomass can subsequently be decreased as well (Novotny and Olem, 1994). In most efforts to control eutrophication processes in water bodies, emphasis is placed on the limiting nutrient. This is not always the case, however. For example, if nitrogen is the limiting nutrient, it still may be more efficient to control phosphorus loads if the nitrogen originates from difficult to control sources such as nitrates in ground water.

In most fresh water bodies, phosphorus is the limiting nutrient for aquatic growth. In some cases, however, the determination of which nutrient is the most limiting is difficult. For this reason, the ratio of the amount of N to the amount of P is often used to make this determination (Thomann and Mueller, 1987). If the N/P ratio is less than 10, nitrogen is limiting. If the N/P ratio is greater than 10, phosphorus is the limiting nutrient. In the case of West Branch Sub-basin #3, the N/P ratio is approximately 13, which points to phosphorus as the limiting nutrient. It is therefore assumed that controlling the phosphorus loading to West Branch Sub-basin #3 will limit plant growth and result in raising the dissolved oxygen level.

C7.1.4 Watershed Assessment and Modeling

The AVGWLF model was run for both West Branch Sub-basin #3 and the reference watershed to establish existing loading conditions under existing land cover use conditions in each watershed. Using the refined parameter estimates based on the calibration results, AVGWLF was re-run for West Branch Sub-basin #3. Based on the use of 20 years of historical weather data, the mean annual loads for sediments, N and P for the impaired and reference watersheds were calculated as shown Tables C7.2 and C7.3, respectively. Table C7.4 presents an explanation of the header information contained in Tables C7.2 and C7.3. Modeling output for West Branch Sub-basin #3 and the reference watershed is presented in Appendix F.

Table C7.2. Loading Values for West Branch Sub-basin #3							
Land Use Category	*Area (acres)*	*Total P (lbs/yr)*	*Unit Area P Load (lbs/acre/ yr)*	*Total N (lbs/yr)*	*Unit Area N Load (lbs/acre/yr)*	*Sediment Load (lbs/year)*	*Unit Area Sediment Load (lbs/acre/yr)*
Hay/Past	200	44	0.22	367	1.84	7,108	35.54
Cropland	1,089	827	0.76	5,317	4.87	706,203	648.49
Coniferous For	27	0	0.00	3	0.11	44	1.63
Mixed Forest	237	1	0.00	28	0.12	795	3.35
Deciduous For	881	6	0.00	107	0.12	4,128	4.69
Transitional	7	6	0.86	52	7.4	5,541	791.57
Lo Intensity Dev	64	0	0.00	0	0	1,302	20.34
Hi Intensity Dev	123	0	0.00	0	0	221	18.41
Stream Bank		68		310		205,077	
Groundwater		476		9,684			
Point Source		0		0			
Septic Systems		9		2,329			
Total	2,517	1,437	0.57	18,195	7.23	930,419	369.65

Table C7.3. Loading Values for the Reference Watershed							
Land Use Category	*Area (acres)*	*Total P (lbs/yr)*	*Unit Area P Load (lbs/acre/ yr)*	*Total N (lbs/yr)*	*Unit Area N Load (lbs/acre/ yr)*	*Sediment Load (lbs/year)*	*Unit Area Sediment Load (lbs/acre/yr)*
Hay/Past	185	44	0.24	364	1.97	6,578	35.56
Cropland	968	558	0.58	4,033	4.17	325,960	336.74
Coniferous For	54	0	0.00	7	0.13	132	2.44
Mixed For	131	1	0.00	16	0.13	463	3.53
Deciduous For	1074	8	0.00	143	0.13	6,623	6.17
Lo Int Dev	40	0	0.00	0	0.00	2,008	50.20
Hi Int Dev	2	0	0.00	0	0.00	66	33.0
Stream Bank		46		213		142,384	
Groundwater		520		10,574			
Point Source		0		0			
Septic Systems		23		2,146			
Total	2,454	1,200	0.49	17,496	7.13	484,214	197.32

Table C7.4. Header Information for Tables C7.2 and C7.3.	
Land Use Category	The land cover classification that was obtained by from the MRLC database
Area (acres)	The area of the specific land cover/land use category found in the watershed.
Total P	The estimated total phosphorus loading that reaches the outlet point of the watershed that is being modeled. Expressed in lbs./year.
Unit Area P Load	The estimated loading rate for phosphorus for a specific land cover/land use category. Loading rate is expressed in lbs/acre/year
Total N	The estimated total nitrogen loading that reaches the outlet point of the watershed that is being modeled. Expressed in lbs./year.
Unit Area N Load	The estimated loading rate for nitrogen for a specific land cover/land use category. Loading rate is expressed in lbs/acre/year
Total Sediment	The estimated total sediment loading that reaches the outlet point of the watershed that is being modeled. Expressed in lbs./year.
Unit Area Sediment Load	The estimated loading rate for sediment for a specific land cover/land use category. Loading rate is expressed in lbs/acre/year

C7.2 LOAD ALLOCATION PROCEDURE FOR NUTRIENT AND SEDIMENT TMDLs

The load allocation and reduction procedures were applied to all of West Branch Sub-basin #3. The load reduction calculations in West Branch Sub-basin #3 are based on the current loading rates for phosphorus and sediments in the reference watershed. Based on biological assessment, it was determined that the reference watershed was attaining its designated uses. The phosphorus and sediment loading rates were computed for the reference watershed using the AVGWLF model. These loading rates were then used as the basis for establishing the TMDLs for West Branch Sub-basin #3.

The equations defining TMDLs for sediments and nutrients are as follows:

$$TMDL = MOS + LA + WLA \qquad (1)$$
$$LA = ALA - LNR \qquad (2)$$

TMDL is the TMDL total load. The LA (load allocation) is the portion of Equation (1) that is typically assigned to non-point sources. The MOS (margin of safety) is the portion of loading that is reserved to account for any uncertainty in the data and computational methodology used for the analysis. The WLA (Waste Load Allocation) is the portion of this equation that is typically assigned to point sources. The adjusted load allocation (ALA) is the load originating from sources (Equation 2) that needs to be reduced by the non-contributing sources (LNR) for West Branch Sub-basin #3 to meet water quality goals.

In this case, sediment loads from non-point sources were assigned to the WLA category. This was done for two primary reasons: 1) because "land development" and "construction" were listed as primary sources of sediment to impaired streams in the sub-watershed, and 2) to be consistent with EPA guideance on how to handle sediment in watersheds where MS4 regulations are applicable. Phosphorus loads originating from agricultrural land, however, was assigned to the LA category. Details of TMDL, MOS, LA, LNR, and ALA computations are presented below.

C7.2.1 TMDL Total Loads

The TMDL loads for both pollutants of concern were computed in the same manner. These loads were obtained by multiplying each pollutant unit loading rate in the reference watershed by the total watershed area of West Branch Sub-basin #3. This information is presented in Table C7.5.

Table C7.5. TMDL Total Load Computation

Type of Pollutant	*Unit Area Loading Rate in Reference Watershed (lbs/acre/yr)*	*Total Watershed Area in West Branch Sub-basin #3 (acres)*	*TMDL Total Load (lbs/yr)*
Phosphorus	0.49	2,517	1,233
Sediment	197.32	2,517	496,654

C7.2.2 Margin of Safety

The Margin of Safety (MOS) for this analysis is explicit. Ten percent of each of the TMDLs was reserved as the MOS.

Phosphorus - 1,233 *lbs/yr x 0.1 = 123 lbs/yr* *(3)*

Sediment - 496,654*lbs/yr x 0.1 =* 49,665 *lbs/yr* *(4)*

C7.2.3 Load Allocation for Phosphorus

The load allocation (LA), consisting of all non-point sources in the watershed, was computed by subtracting the margin of safety and the waste load allocation (WLA) from the TMDL total load. (Notice that there is no waste load allocation for phosphorus in this sub-watershed).

LA (Phosphorus) = 1,233 *lbs/yr – 123 lbs/yr = 1,110 lbs/yr* *(5)*

C7.2.4 Adjusted Load Allocation for Phosphorus

The adjusted load allocation (ALA) is the actual load allocation for sources that will need reductions. It is computed by subtracting loads from non-point sources that are not considered in the reduction scenario (LNR). These are loads from all non-point sources in Table C7.2 except those from agricultural land uses (Hay/Pasture, Row Crops), land development, and stream bank erosion. Therefore, using data in Table C7.2,

$$LNR\ (Phosphorus) = 1\ lbs/yr + 6\ lbs/yr + 6\ lbs/yr + 476\ lb/yr + 9\ lbs/yr = 498\ lb/yr \quad (6)$$

$$ALA\ (Phosphorus) = 1{,}110\ lbs/yr - 498\ lbs/yr = 612\ lbs/yr \quad (7)$$

The ALA computed above is the portion of the load that is available to allocate among contributing sources (Hay/Pasture, Cropland), land development and streambank erosion as described in Section C7.2.6. Not all land use/source categories were included in the allocation because they are difficult to control, or provide an insignificant portion of the total load (e.g., transition land use).

C7.2.5 Waste Load Allocation for Sediment

For the purposes of this TMDL assessment, sediment loads from all sources have been assigned to the waste load allocation (WLA) category to be consistent with EPA guidance on how to handle sediment loads in areas where MS4 regulations apply. Therefore, the load allocation (LA) for sediment in this case is equal to zero. Allowing for an explicit 10% MOS, the target WLA is re-computed as:

$$WLA\ (Sediment) = 496{,}654\ lbs/yr - 49{,}665\ lbs/yr = 446{,}989\ lbs/yr \quad (8)$$

Tables that can be used to cross-reference sub-areas with municipalities in the Neshaminy Creek basin, as well as a summary of sediment-related WLAs, can be found in Appendix E. A map showing the overlap between sub-basin and municipal boundaries within the entire Neshaminy Creek basin is also included in this same appendix.

Table C7.6 below presents the TMDLs for West Branch Sub-basin #3.

Table C7.6. Summary of TMDLs for West Branch Sub-basin #3 (lbs/yr)

Pollutant	TMDL	MOS	WLA	LA	LNR	ALA
Phosphorus	1,233	123	0	1,110	498	612
Sediment	496,654	49,665	446,989	-	-	-

C7.2.6 Load Reduction Procedures for Phosphorus

Phosphorus loads obtained in the previous step (Section C7.2.4) were allocated among the remaining land use/sources of the impaired watershed according to the Equal Marginal Percent Reduction (EMPR) method. EMPR is carried out using an Excel Worksheet in the following manner:

1) Each land use/source load is compared with the total allocable load to determine if any contributor would exceed the allocable load by itself. The evaluation is

carried out as if each source is the only contributor to the pollutant load to the receiving waterbody. If the contributor exceeds the allocable load, that contributor would be reduced to the allocable load. This is the baseline portion of EMPR.

2) After any necessary reductions have been made in the baseline the multiple analysis is run. The multiple analysis will sum all of the baseline loads and compare them to the total allocable load. If the allocable load is exceeded, an equal percent reduction will be made to all contributors' baseline values. After any necessary reductions in the multiple analysis, the final reduction percentage for each contributor can be computed.

The load allocation and EMPR procedures were performed using an Excel Worksheet and results are presented in Appendix G. Table C7.7 provides load allocation by considering all land uses in West Branch Sub-basin #3. In this case, land uses/sources that were not part of the allocation are carried through at their existing loading values.

The total allowable phosphorus load in West Branch Sub-basin #3 when all land use/cover sources are considered is 1,110 pounds per year. In order for all stream segments to attain their specific uses, the total phosphorus load should be reduced from 1,437 pounds per year by a factor of 23%.

C7.2.7 Load Reduction Procedures for Sediment

In contrast to the approach used for phosphorus, the allocation of sediment among contributing sources in West Branch Sub-Basin #3 was done by reducing each source equally on a percentage basis. Based on the target WLA of 446,989 lbs/year described previously, the computed load allocations are those shown in Table C7.7.

The total allowable sediment load in West Branch Sub-basin #3 when all sources are considered is 446,989 pounds per year. In order for all stream segments to attain their specific uses, sediment loads should be reduced from 960,419 pounds per year by a factor of 52%.

C7.3 CONSIDERATION OF CRITICAL CONDITIONS

The AVGWLF model is a continuous simulation model, which uses daily time steps for weather data and water balance calculations. Monthly calculations are made for sediment and nutrient loads, based on the daily water balance accumulated to monthly values. Therefore, all flow conditions are taken into account for loading calculations. Because there is generally a significant lag time between the introduction of sediment and nutrients to a waterbody and the resulting impact on beneficial uses, establishing these TMDLs using average annual conditions is protective of the waterbody.

C7.4 CONSIDERATION OF SEASONAL VARIATIONS

The continuous simulation model used for this analysis considers seasonal variation through a number of mechanisms. Daily time steps are used for weather data and water balance calculations. The model requires specification of the growing season, and hours of daylight for each month. The model also considers the months of the year when manure is applied to the land. The combination of these actions by the model accounts for seasonal variability.

C7.5 REASONABLE ASSURANCE OF IMPLEMENTATION

Sediment reductions in the TMDLs are allocated to all sources of upland and stream bank erosion in the watershed. Implementation of best management practices (BMPs) in the affected areas to increase infiltration and sediment control measures should achieve the loading reduction goals established in the TMDLs. Substantial reductions in the amount of sediment reaching the streams can be made through the installation of drainage controls such as detention ponds, sediment ponds, infiltration pits, dikes and ditches, and riparian buffers. These BMPs range in efficiency from **20% to 70%** for sediment reduction. The implementation of such BMPs will likely occur in the watershed as a result of PaDEP's Proposed Comprehensive Stormwater Management Policy. When approved, this new policy will require affected communities to implement BMPs to address stormwater control that will "reduce pollutant loadings to streams, recharge groundwater tables, enhance stream base flow during times of drought and reduce the threat of flooding and stream bank erosion resulting from storm events." Over the next year and one-half, PaDEP will be developing a "Phase II" program for NPDES discharges from small construction sites, additional industrial activities, and for the 700 municipalities subject to the requirements for separate storm sewer systems (MS4). All of the municipalities located within West Branch Sub-basin #3 will be affected by this policy, which has been included in Appendix E. Tables for cross-referencing sub-areas with municipalities, as well as summarizing sediment WLAs, have also been included in this appendix.

Implementation of BMPs aimed at sediment reduction will also assist in the reduction of phosphorus originating from transitional land uses and stream bank erosion. Other possibilities for attaining the desired reductions in phosphorus and sediment include streambank stabilization and fencing. Further ground verification will be performed in order to assess both the extent of existing BMPs, and to determine the most cost-effective and environmentally protective combination of BMPs required to meet the nutrient and sediment reductions outlined in this report.

Similarly, implementation of best management practices (BMPs) in the agricultural areas to increase infiltration and decrease sediment and phosphorus loss in these areas should achieve the phosphorus loading reduction goals established in this watershed. Substantial reductions in the amount of dissolved and sediment-borne phosphorus reaching the stream can be made through the implementation of various field-based measures such as conservation tillage, cover crops and nutrient management, as well as via the use of riparian stream buffers. These BMPs have been shown to range in efficiency from about **20% to 70%** for phosphorus reduction. It has been, and will continue to be, PaDEP's intent to encourage the implementation of such BMPs in the watershed through projects funded by the State's Growing Greener Program.

C7.6 PUBLIC PARTICIPATION

Notice of the draft TMDLs will be published in the *PA Bulletin* and local newspapers with a 30-day comment period provided. A public meeting with watershed residents will be held to discuss the TMDLs. Notice of final TMDL approval will be posted on the Department website.

Table C7.7. Load Allocation by Each Land Use/Source									
		Phosphorus				**Sediment**			
Source	*Area (Acres)*	*Unit Area Loading Rate (lbs/ac)*	*Annual average load (lbs/yr)*	*LA (annual average) (lbs/year)*	*Reduction - % -*	*Unit Area Loading Rate (lbs/ac/yr)*	*Annual average load (lbs/yr)*	*WLA (annual average) (lbs/yr)*	*Reduction - % -*
Hay/Past	200	0.22	44	34	23	35.54	7,108	3,415	52
Cropland	1,089	0.76	827	528	36	648.49	706,203	339,271	52
Coniferous	27	0.00	0	0	0	1.63	44	21	52
Mixed For	237	0.00	1	1	0	3.35	795	382	52
Deciduous	881	0.00	6	6	0	4.69	4,128	1,983	52
Transition	7	0.86	6	6	0	791.57	5,541	2,662	52
Lo Intens Dev	64	0.00	0	0	0	20.34	1,302	625	52
Hi Intens Dev	123	0.00	0	0	0	18.41	221	106	52
Stream Bank			68	52	23		205,077	98,523	52
Groundwater			476	476	0				
Point Source			0	0	0				
Septic Systems			9	9	0				
	2,517	**0.57**	**1,437**	**1,110**	**23**	**369.65**	**930,419**	**446,989**	**52**

C8.0 Total Maximum Daily Loads (TMDLs) Development Plan for Sub-Basin #4 of West Branch Neshaminy Creek

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EXECUTIVE SUMMARY

West Branch Sub-basin #4 is about 15 square miles in size, and is evenly divided between Bucks and Montgomery Counties. This particular sub-basin consists of the main stem of West Branch of Neshaminy Creek and several unnamed tributaries. The protected uses of the watershed are water supply, recreation, and aquatic life. Its aquatic use is warm water fishes and migratory fishes.

Total Maximum Daily Loads (TMDLs) apply to about 22.8 miles of streams within this basin (Stream Segment ID#s 980205-1211-GLW, 980202-1040-GLW, 980202-1043-GLW, and 980205-1430-GLW). They were developed to address the impairments noted on Pennsylvania's 1996 and 2002 Clean Water Act Section 303(d) Lists. The impairments addressed in this particular section are those caused by sediment loads from agriculture in the watershed. Excessive algal growth (i.e., nutrients) from agriculture are addressed in this section as well. However, nutrients/excessive algal growth due to municipal point sources are addressed separately in Section D.

Pennsylvania does not currently have water quality criteria for sediment and nutrients. For this reason, we developed a reference watershed approach to identify the TMDL endpoints or water quality objectives for sediment and non-point source nutrients in the impaired segments of West Branch Sub-basin #4. Since most of the phosphorus reaching impaired segments appears to be attached to sediment originating from eroded upland areas, it was determined that a reduction in sediment loads would also reduce phosphorus loads in this watershed. Based upon comparison to a similar, non-impaired watershed, it was estimated that the sediment loading that will meet the water quality objectives for West Branch Sub-basin #4 is 5,998,845 lbs per year. It is assumed that West Branch Sub-basin #4 will support its aquatic life uses when this value is met. The TMDL for West Branch Sub-basin #4 is allocated as shown in the table below.

Summary of Sediment TMDLs for West Branch Sub-basin #4 (lbs/yr)

Pollutant	TMDL	MOS	WLA	LA	LNR	ALA
Sediment	5,998,845	599,885	-	5,398,990	570,350	4,828,640

The TMDL for sediment is allocated to agricultural land and stream bank erosion, with 10% of the TMDL total load reserved as a margin of safety (MOS). The adjusted load allocation (ALA) is that load attributed to agricultural land and streambank erosion, and is computed by subtracting loads that do not need to be reduced (LNR) from the TMDL total values. The TMDL covers a total of 22.8 stream miles, and establishes a 45% reduction from the current sediment load of 9,859,400 pounds per year (which also accounts for the 10% MOS).

C8.0 INTRODUCTION

C8.0.1 Watershed Description

The following discussion provides information on the physical characteristics of West Branch Sub-basin #4 including its location, land use distribution, and geology. West Branch Sub-basin #4 is located in the Piedmont physiographic province and in Bucks and Montgomery Counties. It covers an area of approximately 15 square miles. The streams in West Branch Sub-basin #4 drain into the West Branch of Neshaminy Creek from the north. The watershed is located east of the town of New Britain and is bounded by Pennsylvania Route 309 to the west, Route 152 to the east, and Route 202 to the south. Figure C8.1 shows the watershed boundary and its location. The designated uses of the watershed include water supply, recreation and aquatic life. As listed in the Title 25 PA Code Department of Environmental Protection Chapter 93, Section 93.o (Commonwealth of PA, 1999), the designated aquatic life use for the West Branch Sub-basin #4 is warm water fishes and migratory fishes.

The primary land use in West Branch Sub-basin #4 is agriculture (35%) (with areas adjacent to the stream used for cropland and pasture) and land development (29%). It was found also from a field survey of the watershed that cattle generally have free access to the stream. The majority of the streams had no protected riparian zone. The 1994 survey showed that nutrients from agricultural activities and municipal point sources were causing increased algae growth. It also found that sediment deposited in large quantities on the streambed was degrading the habitat of bottom-dwelling macroinvertebrates.

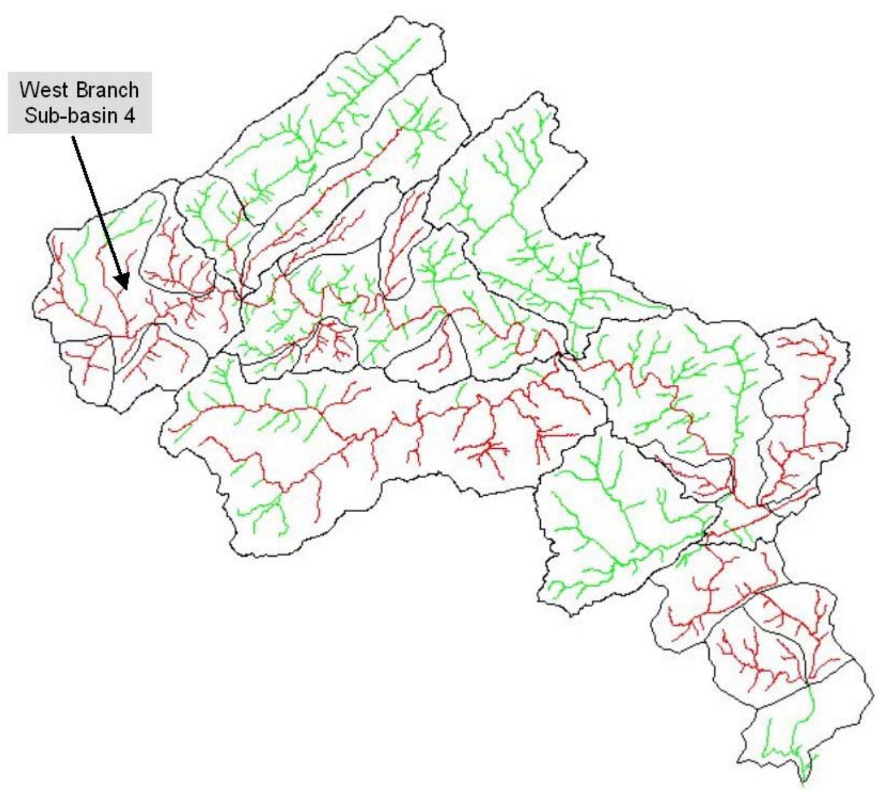

Figure C8.1. West Branch Sub-basin #4 Watershed.

In terms of subsurface geology, West Branch Sub-basin #4 is primarily underlain by a shale formation. The bedrock geology affects primarily surface runoff and background nutrient loads through its influences on soils and landscape as well as fracture density and directional permeability. Soils are mostly sandy and very erodible, as indicated by a high average K factor (0.37). Characteristics of Sub-basin #4, as well as those of the reference watershed chosen for further analysis (see later discussion), are summarized in Table C8.1.

Table C8.1. Physical Characteristic Comparisons between West Branch Sub-basin #4 and Reference Watershed

Attribute	**West Branch Sub-basin #4**	**Reference Watershed**
Physiographic Province	Piedmont	Piedmont
Area (square miles)	15	15
Predominant Land Uses	Agriculture (35%) Developed (29%) Forested (36%)	Agriculture (49%) Developed (3%) Forested (46%)
Predominant Geology	Shale (100%)	Shale (100%)
Soils - Dominant HSG	C	C
- K Factor	0.37	0.37
20-Year Average Rainfall (in)	40.6	40.6
20-Year Average Runoff (in)	4.5	4.1

C8.0.2 Surface Water Quality

Total Maximum Daily Loads or TMDLs were developed for West Branch Sub-basin #4 to address the impairments noted on Pennsylvania's 1996 and 2002 Clean Water Act Section 303(d) Lists (see Table A1 in section A1.0). It was first determined that West Branch Sub-basin #4 was not meeting its designated water quality uses for protection of aquatic life in 1994 based on aquatic biological survey. The 2001 survey found that that the stream was still impaired. As a consequence, Pennsylvania listed stream segments in West Branch Sub-basin #4 on the 1996 and 2002 Section 303(d) List of Impaired Waters.

The 1996 303 (d) List reported 7.7 miles of West Branch Sub-basin #4 (Stream Segment ID# 980202-1043-GLW) to be impaired by nutrients from municipal point sources. The 2002 303(d) List reported an additional 15.1 miles (Stream Segment ID#s 980205-1430-GLW, 980205-1211-GLW and 980202-1040-GLW) and additional impairments from siltation, excessive algae growth, and water/flow variability from agriculture, municipal point sources and land development and urban runoff/storm sewers.

C8.1 APPROACH TO TMDL DEVELOPMENT

C8.1.1 TMDL Endpoints

The TMDL described herein addresses sediment and non-point sources of nutrients. The impairments related to municipal point source discharges (specifically excessive algal growth) are dealt with in Section D. Because neither Pennsylvania nor EPA have water quality criteria for sediment or nutrients, we had to develop a method to determine water quality objectives for these parameters that would result in the impaired stream segments attaining their designated uses. The method employed for this TMDL is termed the "reference watershed approach." With the reference watershed approach, a pair of watersheds is compared; with one attaining its uses and one that is impaired based on biological assessment. Both watersheds should have similar land use/cover distributions. Other features such as base geologic formation should be matched to the greatest extent possible; however, most variations can be adjusted in the model. The objective of the process is to reduce the loading rate of nutrients and/or sediments in the watershed containing the impaired stream segment(s) to a level equivalent to or slightly lower than the loading rate in the watershed with the non-impaired, reference stream segment(s). The underlying assumption is that this load reduction will allow biological health to return to the impaired stream segments. The TMDL to be addressed in this section relates to the stream impairments found in the 1996 and 2002 303(d) Lists, and is described in greater detail below.

As discussed previously in Section B1.5, elevated nutrient loads to streams (nitrogen and phosphorus in particular) can lead to increased productivity of plants and other organisms (Novotny and Olem, 1994). As also described in Section D2.1, phosphorus was determined to be the limiting nutrient in the Neshaminy Creek watershed as a whole. Given that, phosphorus was the nutrient of focus in developing the TMDL for this sub-basin as well. Based on the field work undertaken as part of the initial aquatic biological surveys, it was determined that agricultural activities were the primary cause of non-point source-related algal growth in impaired streams in this watershed. Since most phosphorus transported from agricultural land is in the form of sediment-bound phosphorus, it is believed that the reduction of sediment from such areas will help mitigate problems with excessive algal growth and organic enrichment caused by elevated phosphorus levels. Consequently, the reduction of sediment was the focus of this particular TMDL.

C8.1.2 Selection of the Reference Watershed

In general, three factors should be considered when selecting a suitable reference watershed. The first factor is to use a watershed that has been assessed by the Department using the Unassessed Waters Protocol and has been determined to attain water quality standards. The second factor is to find a watershed that closely resembles the watershed being assessed (i.e., West Branch Sub-basin #4) with respect to physical properties such as land cover/land use, physiographic province, and geology. Finally, the size of the reference watershed should be within 20-30% of the impaired watershed area. The search for a reference watershed that would satisfy the above characteristics was done by means of a desktop screening using several GIS coverages including the Multi-Resolution Land Characteristics (MRLC) Landsat-derived land cover/use grid, the Pennsylvania's 305(b) assessed streams database, and geologic rock types.

A watershed that would be similar to West Branch Sub-basin #4 Watershed in terms of land use distribution could not be found due to the fact that other watersheds that have similar levels of agricultural land use and land development are typically also impaired. Therefore, the watershed used as a reference for West Branch Sub-basin #4 has less development. The watershed used as a reference for the West Branch Sub-basin #4 is comprised of the Lashaka/Mill Creek watershed. This watershed is located in the same physiographic province and State Water Plan as West Branch Sub-basin #4, and is in fact a sub-watershed of the Neshaminy Creek watershed. Table C8.1 compares the two watersheds in terms of their size, location, and other physical characteristics. All reference watershed stream segments have been assessed and were found to be unimpaired. Figure C8.2 shows the reference watershed boundary and its location in Bucks County.

An analysis of the MRLC land use/cover layer revealed that land use/cover distributions in both watersheds are somewhat similar, although the reference watershed is less developed. The surficial geology of both West Branch Sub-basin #4 and the reference watershed is shale. The bedrock geology affects primarily surface runoff and background nutrient loads through its influences on soils and landscape as well as fracture density and directional permeability. A look at these attributes in Table C8.1 indicates that these watersheds compare very well in terms of average runoff, precipitation, and soil K factor.

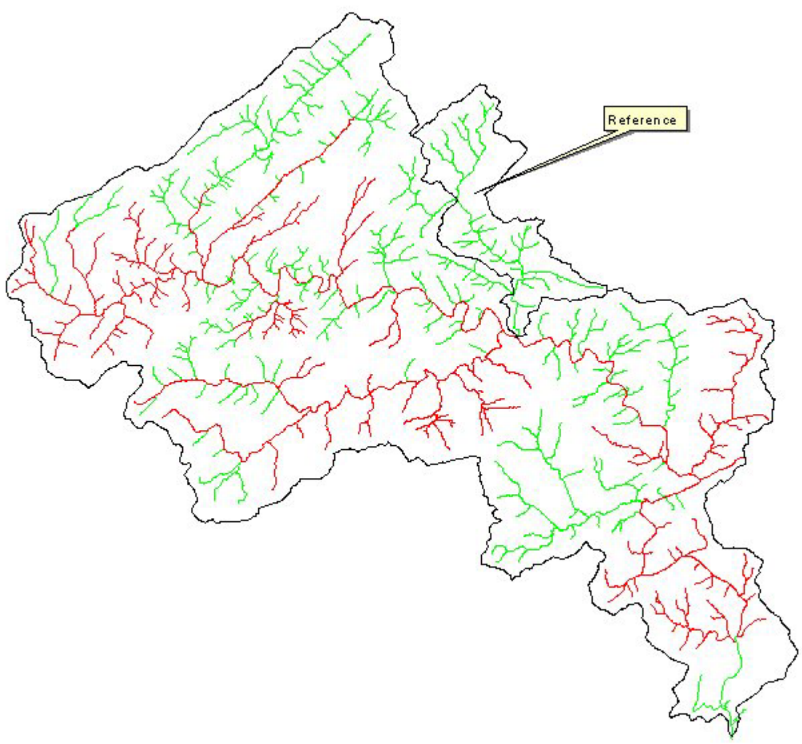

Figure C8.2. Reference Watershed Location.

C8.1.3 Water/Flow Variability and Flow Alterations Resulting from Urban Runoff/Storm Sewers and Land Development

TMDLs were not determined for water/flow variability and flow alterations. It was assumed that addressing sediment loads through the use of various BMPs will at the same time reduce water flow variability/alterations within the watershed.

C8.1.4 Siltation Due to Agricultural Sources

The 1994 and 2001 surveys showed that siltation originating from agricultural activities in the watershed was a primary cause of impairment of West Branch Sub-basin #4 stream segments. Sediments deposited in large quantities on the streambed were degrading the habitat of bottom-dwelling macroinvertebrates. This TMDL addresses sediments from agricultural activities. Because neither Pennsylvania nor EPA have water quality criteria for sediments, we had to develop a method to determine water quality objectives for this parameter that would result in the impaired stream segments attaining their designated uses.

C8.1.5 Excessive Algae Growth/Nutrients from Agriculture and Municipal Point Source Discharges

As indicated earlier, West Branch Sub-basin #4 was also listed as being impaired due to problems associated with nutrients/excessive algal growth caused by agricultural activities and municipal point source discharges in the watershed. Due to the different modeling approach used to assess point source problems, the impairment due to municipal point source discharges is not addressed in this section; rather, it is discussed later in Section D. However, the impairment due to agricultural activities is addressed in this section. More specifically, emphasis is placed on the reduction of the limiting nutrient (phosphorus) via the reduction of sediment.

C8.1.6 Watershed Assessment and Modeling

Using the refined parameter estimates based on the calibration results, the AVGWLF model was run for both West Branch Sub-basin #4 and the reference watershed to establish sediment loads under existing land cover use conditions in each watershed. Based on the use of 20 years of historical weather data, the mean annual sediment loads for the impaired and reference watersheds are shown Tables C8.2 and C8.3, respectively. Table C8.4 presents an explanation of the header information contained in Tables C8.2 and C8.3. Modeling output for West Branch Sub-basin #4 and the reference watershed is presented in Appendix F.

Table C8.2. Loading Values for West Branch Sub-basin #4

Land Use Category	*Area (acres)*	*Sediment Load (lbs/year)*	*Unit Area Sediment Load (lbs/acre/yr)*
Hay/Pasture	840	45,980	54.7
Cropland	2,983	3,938,020	1320.2
Coniferous For	489	2,700	5.5
Mixed Forest	408	2,120	5.2
Deciduous For	912	6,540	7.2
Unpaved Roads	3	1,060	353.3
Transitional Land	457	471,680	1032.1
Lo Intensity Dev	2,474	67,560	27.3
Hi Intensity Dev	882	16,460	18.66
Stream Bank		5,307,280	
Groundwater			
Point Source			
Septic Systems			
Total	9,447	9,859,400	1043.7

Table C8.3. Loading Values for the Reference Watershed

Land Use Category	*Area (acres)*	*Sediment Load (lbs/year)*	*Unit Area Sediment Load (lbs/acre/yr)*
Hay/Pasture	1,105	47,300	42.8
Cropland	4,297	3,842,420	894.2
Coniferous Forest	667	4,180	6.3
Mixed Forest	754	6,720	8.9
Deciduous Forest	1,848	21,880	11.8
Unpaved Roads	3	1,120	373.3
Quarries	27	22,180	821.5
Transitional Land	670	648,860	968.4
Low Intensity Dev	331	6,220	18.8
Stream Bank		1,559,800	
Groundwater			
Point Source			
Septic Systems			
Total	9701	6,160,400	635.0

Table C8.4. Header Information for Tables C8.2 and C8.3.	
Land Use Category	The land cover classification that was obtained by from the MRLC database
Area (acres)	The area of the specific land cover/land use category found in the watershed.
Total P	The estimated total phosphorus loading that reaches the outlet point of the watershed that is being modeled. Expressed in lbs./year.
Unit Area P Load	The estimated loading rate for phosphorus for a specific land cover/land use category. Loading rate is expressed in lbs/acre/year
Total N	The estimated total nitrogen loading that reaches the outlet point of the watershed that is being modeled. Expressed in lbs./year.
Unit Area N Load	The estimated loading rate for nitrogen for a specific land cover/land use category. Loading rate is expressed in lbs/acre/year
Total Sediment	The estimated total sediment loading that reaches the outlet point of the watershed that is being modeled. Expressed in lbs./year.
Unit Area Sediment Load	The estimated loading rate for sediment for a specific land cover/land use category. Loading rate is expressed in lbs/acre/year

C8.2 LOAD ALLOCATION PROCEDURE FOR SEDIMENT TMDL

The load allocation and reduction procedures were applied to all of West Branch Sub-basin #4. The load reduction calculations in West Branch Sub-basin #4 are based on the current sediment loading rate in the reference watershed. Based on biological assessment, it was determined that the reference watershed was attaining its designated uses. This loading rate was then used as the basis for establishing the sediment TMDL for West Branch Sub-basin #4.

The basic equation defining TMDLs for sediments and nutrients are as follows:

$$TMDL = MOS + LA + WLA \qquad (1)$$

$$LA = ALA - LNR \qquad (2)$$

TMDL is the TMDL total load. The LA (load allocation) is the portion of Equation (1) that is typically assigned to non-point sources. The MOS (margin of safety) is the portion of loading that is reserved to account for any uncertainty in the data and computational methodology used for the analysis. The WLA (Waste Load Allocation) is the portion of this equation that is typically assigned to point sources. The adjusted load allocation (ALA) is the load originating from sources (Equation 2) that needs to be reduced by the non-contributing sources (LNR) for West Branch Sun-basin #4 to meet water quality goals. Therefore, it is the load that originates from agricultural sources that have contributed to water quality problems identified in this watershed. Details of how specific components of the overall TMDL calculation were derived are presented below.

C8.2.1 TMDL Total Load

The first step was to determine the TMDL total target load for West Branch Sub-basin #4, the impaired watershed. This value was obtained by multiplying the unit area loading rate for sediment in the reference watershed by the total watershed area of West Branch Sub-basin #4. This information is presented in Table C8.5.

Table C8.5. TMDL Total Load Computation

Type of Pollutant	*Unit Area Loading Rate in Reference Watershed (lbs/acre/yr)*	*Total Watershed Area in West Branch Sub-basin #4 (acres)*	*TMDL Total Load (lbs/yr)*
Sediment	635.0	9,447	5,998,845

C8.2.2. Margin of Safety

The Margin of Safety (MOS) for this analysis is explicit. Ten percent of each of the TMDLs was reserved as the MOS.

MOS (Sediment): 5,998,845 lbs/yr x 0.1 = 599,855 lbs/yr (3)

C8.2.3 Load Allocation

The load allocation (LA), consisting of all nonpoint source loads in the watershed, was computed by subtracting the margin of safety and the waste load allocation (which was zero for sediment in this case) from the TMDL total load.

LA (Sediment): 5,998,845 lbs/yr – 599,855 lbs/yr = 5,398,990 lbs/yr (4)

C8.2.4 Adjusted Load Allocation

The adjusted load allocation (ALA) is the actual load allocation for sources that will need reductions. It is computed by subtracting loads from non-point sources that are not considered in the reduction scenario (LNR). These are loads from all non-point sources in Table C13.2 except those from agricultural land uses (Hay/Pasture, Row Crops, and Streambank Erosion). (Note: Streambank erosion was included in the load allocation in this case since this problem typically occurs in agricultural areas, and is a source that can be controlled via the use of BMPs in agricultural areas). Therefore, using data in Table C13.2,

LNR (Sediments) = 2,700 lbs/yr + 2,120 lbs/yr 2,230 lb/yr + 6,540 lb/yr
+ 1,060 lbs/yr + 471,680 lbs/yr + 67,560 lb/yr + 16,460 lb/yr
= 570,350 lbs/yr (6)

ALA (Sediments) = 5,398,990 lbs/yr – 570,350 lbs/yr = 4,828,640 lbs/yr (7)

Table C8.6 below presents TMDL results for the West Branch Sub-basin #4..

Table C8.6. Summary of TMDL for West Branch Sub-basin #4 (lbs/yr)						
Pollutant	**TMDL**	**MOS**	**WLA**	**LA**	**LNR**	**ALA**
Sediment	5,998,845	599,885	-	5,398,990	570,350	4,828,640

The ALA computed above is the portion of the load that is available to allocate among contributing sources (Hay/Pasture, Cropland, and streambank erosion) as described in the next step. Not all land use/source categories were included in the allocation because they are difficult to control, or provide an insignificant portion of the total load (e.g., forested areas). The following section shows the allocation process in detail for the entire watershed.

C8.2.5 Load Reduction Procedures

Sediment loads obtained in the previous step were allocated among the remaining land use/sources of the impaired watershed according to the Equal Marginal Percent Reduction (EMPR) method. EMPR is carried out using an Excel Worksheet in the following manner:

1) Each land use/source load is compared with the total allocable load to determine if any contributor would exceed the allocable load by itself. The evaluation is carried out as if each source is the only contributor to the pollutant load to the receiving waterbody. If the contributor exceeds the allocable load, that contributor would be reduced to the allocable load. This is the baseline portion of EMPR.

2) After any necessary reductions have been made in the baseline the multiple analysis is run. The multiple analysis will sum all of the baseline loads and compare them to the total allocable load. If the allocable load is exceeded, an equal percent reduction will be made to all contributors' baseline values. After any necessary reductions in the multiple analysis, the final reduction percentage for each contributor can be computed.

The load allocation and EMPR procedures were performed using an Excel Worksheet, and results are presented in Appendix G. Table C8.7 provides load allocation by considering all land uses in the watershed. In this case, land uses/sources that were not part of the allocation are carried through at their existing loading values.

The total allowable sediment load in West Branch Sub-basin #4 and its tributaries when all sources are considered (and including the 10% MOS) is 5,398,990 pounds per year. In order for all stream segments to attain their specific uses, the total sediment load should be reduced from 9,859,400 pounds per year by a factor of 45%.

Table C8.7 Load Allocation by Each Land Use/Source					
		Sediment			
Source	*Area (acres)*	*Unit Area Loading Rate (lbs/ac/yr)*	*Annual average load (lbs/yr)*	*ALA (lbs/yr)*	*Reduction (%)*
Hay/Pasture	840	54.7	45,980	23,913	48
Cropland	2,938	1320.2	3,938,020	2,047,498	48
Coniferous For	489	5.5	2,700	2,700	0
Mixed Forest	408	5.2	2,120	2,120	0
Deciduous For	912	7.2	6,540	6,540	0
Unpaved Roads	3	353.3	1,060	1,060	0
Transitional	457	1032.1	471,680	471,680	0
Lo Intensity Dev	2,474	27.3	67,560	67,560	0
Hi Intensity Dev	882	18.6	16,460	16,460	0
Stream Bank			5,307,280	2,759,459	48
Groundwater					
Point Source					
Septic Systems					
Total	9,447	1043.7	9,859,400	5,398,990	**45**

C8.3 CONSIDERATION OF CRITICAL CONDITIONS

The AVGWLF model is a continuous simulation model, which uses daily time steps for weather data and water balance calculations. Monthly calculations are made for sediment and nutrient loads, based on the daily water balance accumulated to monthly values. Therefore, all flow conditions are taken into account for loading calculations. Because there is generally a significant lag time between the introduction of sediment and nutrients to a waterbody and the resulting impact on beneficial uses, establishing these TMDLs using average annual conditions is protective of the waterbody.

C8.4 CONSIDERATION OF SEASONAL VARIATIONS

The continuous simulation model used for this analysis considers seasonal variation through a number of mechanisms. Daily time steps are used for weather data and water balance calculations. The model requires specification of the growing season, and hours of daylight for each month. The model also considers the months of the year when manure is applied to the land. The combination of these actions by the model accounts for seasonal variability.

C8.5 REASONABLE ASSURANCE OF IMPLEMENTATION

Sediment reductions in the TMDL are allocated to agricultural areas and sources of stream bank erosion in the watershed. Implementation of agricultural best management practices (BMPs) in the affected areas to increase infiltration and sediment control measures should achieve the loading reduction goals established in the TMDL. Substantial reductions in the amount of sediment reaching the streams can be made through the planting of riparian buffer zones, contour strips, and cover crops, and conservation tillage. These BMPs range in efficiency from 20% to 70% for sediment reduction. Implementation of BMPs aimed at sediment reduction will also assist in the reduction of phosphorus, which is contributing to algal growth in the streams. Other possibilities for attaining the desired reductions in sediment include streambank stabilization and fencing. Further field verification will be performed in order to assess both the extent of existing BMPs, and to determine the most cost-effective and environmentally protective combination of BMPs required to meet the sediment reductions outlined in this section.

C8.6 PUBLIC PARTICIPATION

Notice of the draft TMDLs will be published in the *PA Bulletin* and local newspapers with a 30-day comment period provided. A public meeting with watershed residents will be held to discuss the TMDLs. Notice of final TMDL approval will be posted on the Department website.