C2.0 Total Maximum Daily Load (TMDL) Development Plan for Little Neshaminy Watershed

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EXECUTIVE SUMMARY

Little Neshaminy Creek is a tributary of Neshaminy Creek, and its watershed covers an area of 43.2 square miles in Bucks and Montgomery Counties. The protected uses of the stream include water supply, recreation, and aquatic life. The designated aquatic uses for Little Neshaminy Creek, its tributary Park Creek, and several unnamed tributaries are warm water fishes and migratory fishes.

Total Maximum Daily Loads (TMDLs) apply to about 47.2 miles of the main stem of Little Neshaminy Creek (Stream Code ID#s 980629-1342-GLW, 980616-1108-GLW, 980616-1316, and 980629-1341), its tributary Park Creek (Stream Code IDs# 980622-1146-GLW, 20010511-1045-GLW, 20010510-1303-GLW, and 980622-1147-GLW), and several unnamed tributaries. They were developed to address the impairments noted on Pennsylvania's 1996, 1998, and 2002 Clean Water Act Section 303(d) Lists. The impairments to be addressed in this particular section are those caused by sediments due to continuing land development in the watershed. Nutrients and DO/BOD from municipal point sources are addressed separately in Section D. Water/flow variability, also listed as a cause of impairment, was not explicitly addressed because it was believed that the implementation of BMPs in the developed (and developing) areas to reduce sediment losses due to upland and streambank erosion 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 the Little Neshaminy watershed. For sediment, the modeling approach was 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 Little Neshaminy Creek, 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 Little Neshaminy is 7,708,168 pounds per year. It is assumed that the Little Neshaminy Creek will support its aquatic life uses when this value is met. The sediment TMDL for Little Neshaminy is allocated as shown in the table below.

Summary of TMDL for Little Neshaminy Creek Watershed (lbs/yr)

Pollutant	Source	TMDL	MOS	WLA	LA	LNR	ALA
Sediment	Upland and stream bank erosion	7,708,168	770,817	6,937,351	-	-	-

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 47.2 miles of the main stem of Little Neshaminy Creek, its tributary Park Creek and several of its unnamed tributaries. The TMDL establishes a reduction for total sediment loading of 17% from the current annual loading of 8,369,480 pounds.

C2.0 INTRODUCTION

C2.0.1 Watershed Description

The following discussion provides information on the physical characteristics of Little Neshaminy and its watershed including location, land use distributions, and geology. Little Neshaminy watershed is located in the Piedmont physiographic province, and is evenly distributed between Bucks and Montgomery counties. It covers an area of approximately 43.2 square miles. Little Neshaminy drains into the main stem of Neshaminy Creek from the west. The watershed is bounded by Pennsylvania Route 309 to the west, Route 232 to the east, and US Interstate 276 (Pennsylvania Turnpike) to the south. It can be accessed in the north-south direction via Route 463 or from Doylestown via Route 611. Figure C2.1 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 uses for the main stem of Little Neshaminy Creek and its tributaries are warm water fishes and migratory fishes.

The current land use distribution in the Little Neshaminy watershed 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 uses in the Little Neshaminy watershed are agriculture (34%), forested land (33%), and developed land (33%). It is important to note that development in the watershed changed from 11.81 to 14.14 square miles from 1992 to 2000, or a 20% increase.

The surficial geology of Little Neshaminy watershed consists primarily of sandstone of the Stockton formation (66%) and the Lockatong shale formation (33%). The Stockton formation is the best source for water supply wells in the area although yields vary considerably. 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 (0.38). Watershed characteristics are summarized in Table C2.1.

C2.0.2 Surface Water Quality

Total Maximum Daily Loads or TMDLs were developed for the Little Neshaminy Creek watershed to address the impairments noted on Pennsylvania's 1996, 1998, and 2002 Clean Water Act Section 303(d) Lists (see Table A1 in section A1.0). It was first determined that Little Neshaminy 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 1997, the creek was evaluated under the Unassessed Waters Program and was found to be still impaired. In 2001, the Department again surveyed the stream and its tributaries. In addition to the main stem of Little Neshaminy and Park Creek, additional stream segments were found to be impaired. As a consequence of the surveys, Pennsylvania listed Little Neshaminy Creek and several of its tributaries on the 1996, 1998, and 2002 Section 303(d) Lists of Impaired Waters.

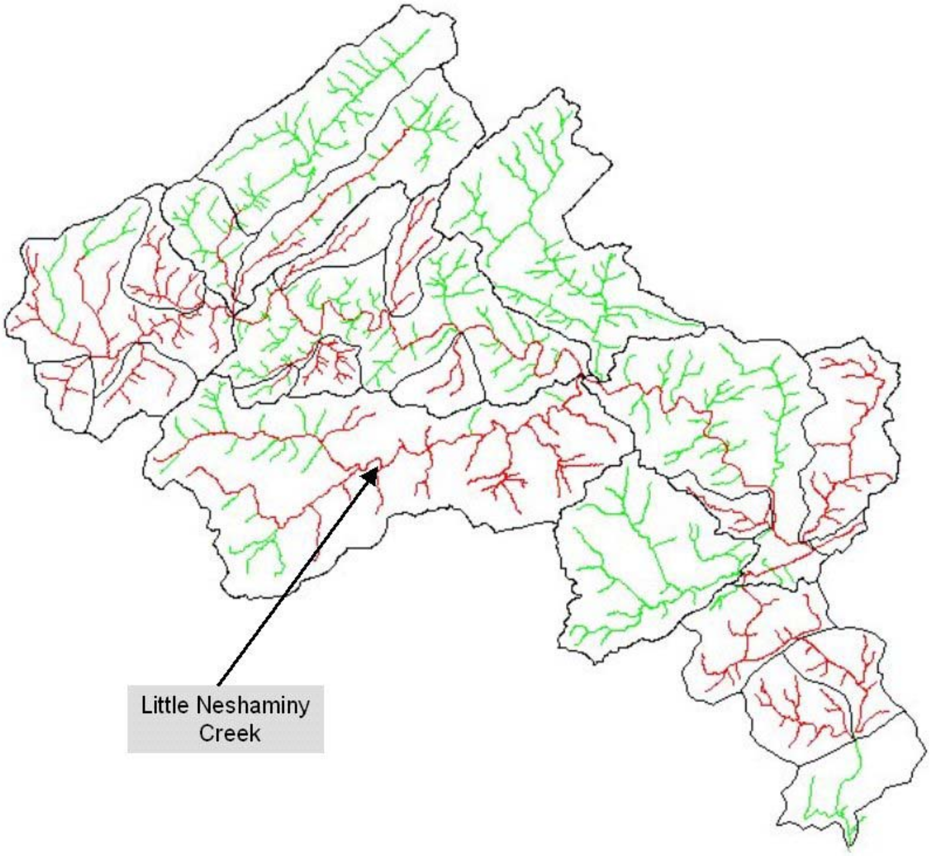

Figure C2.1. Little Neshaminy Creek Watershed.

The 1996 303 (d) List reported 15.7 miles of the Little Neshaminy and 6.2 miles of Park Creek to be impaired by nutrients and DO/BOD. The 1998 303(d) List added 5.5 miles to the Little Neshaminy as being impaired by water/flow variability and siltation, and the 2002 303 (d) List added still more impaired segments. The 2002 list reports a *total* of 37.9 miles of Little Neshaminy Creek (plus several unnamed tributaries) and 9.3 miles of Park Creek (and its two unnamed tributaries) to be impaired by nutrients and DO/BOD from municipal point sources, and by siltation and water/flow variability as a result of urban runoff/storm sewers.

Stream segments of Little Neshaminy Creek and its tributaries 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 Little Neshaminy is the result of years of sediment build-up in the channel bottom that started in the early 1990’s. This sediment 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 20% between 1992 and 2000.

Table C2.1. Physical Characteristics of the Little Neshaminy Creek watershed.

	Little Neshaminy Creek
Physiographic Province	Piedmont
Area (square miles)	43.2
Predominant Land Use	Agriculture (35%) Forested land (32%) Developed land (28%)
Predominant Geology	Sandstone and Shale
Soils	
Dominant HSGs	C
Average K Factor	0.38
20-Year Avg. Rainfall (in)	41.43
20-Year Avg. Runoff (in)	4.45

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, principally 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 the Little Neshaminy Creek watershed. 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 the watershed. Without effective storm water management practices and sediment traps, build-up of sediments will continue to occur in the stream.

C2.1 APPROACH TO TMDL DEVELOPMENT

The present TMDL addresses impairment by sediment in Little Neshaminy stream segments as reported on the 2002 303(d) Lists. The stream water flow variability impairment caused by urban runoff/storm sewer is not explicitly addressed by these TMDLs because it is assumed that management practices that will be used to address storm water runoff and sediment production at new construction sites will reduce problems associated with flow variability as well. This particular TMDL was derived as follows:

C2.1.1 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 urban BMPs will at the same time reduce water flow variability within the watershed.

C2.1.2 Siltation Caused by Urban Runoff/Storm Sewers

The 2001 survey showed that sediment due to soil erosion caused by newly developed land in the watershed was the cause of impairment of Little Neshaminy stream segments. Sediments deposited in large quantities on the streambed were degrading the habitat of bottom-dwelling macroinvertebrates. The TMDLs for Little Neshaminy watershed address 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 to be a cause of impairment during the 1994 survey and 1997 assessments. Year 1992 is considered here to be the benchmark because (as indicated earlier) the analysis of classified satellite images showed that development in the watershed increased by about 20% between 1992 and 2000.

C2.1.3 Nutrients and DO/BOD from Municipal Point Sources

Nutrients and DO/BOD from municipal sources were also listed as the cause of impairment for several stream segments of the Little Neshaminy and its tributaries. Due to the different modeling approach used for point source problems in the Neshaminy Creek watershed, these stream impairments are discussed separately in Section D.

C2.1.4 Oil and Grease from Other Sources

A 0.2-mile segment of Park Creek (Segment ID 20010510-1303-GLW) was also listed in 2002 for an oil and grease impairment from other sources. This was a compliance issue caused by a leaky underground Fuel oil tank. No TMDL is required for this listing.

C2.1.5 Watershed Assessment and Modeling

The AVGWLF model was run for the Little Neshaminy Creek watershed to establish sediment loadings under differing land use/cover conditions (see Section A 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 the Little Neshaminy watershed. Based on the use of 20 years of historical weather data, the mean annual sediment loads for the 1992 and 2000 land use/ cover conditions are shown in Tables C2.2 and C2.3, respectively. The unit area load for sediment 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 C2.4 presents an explanation of the header information contained in Tables C2.2 and C2.3. Modeling output for Little Neshaminy watershed for 1992 and 2000 land use conditions is presented in Appendix F.

Table C2.2. Sediment Loading Values for 1992 Land Use Conditions.

Land Use Category	*Area (acres)*	*Sediment Load (lbs/year)*	*Unit Area Sediment Load (lbs/acre/yr)*
Hay/Pasture	2,726	47,108	17.28
Cropland	7,989	1,286,115	160.99
Coniferous Forest	296	240	0.81
Mixed Forest	1,911	2,250	1.18
Deciduous Forest	6,918	10,504	1.52
Unpaved Roads	7	3,285	469.29
Transition	17	3,991	234.76
Low Intensity Dev	5,640	127,814	22.66
High Intensity Dev	1,758	29,731	16.91
Stream Bank		6,197,130	
Groundwater			
Point Source			
Septic Systems			
Total	27,262	7,708,168	282.75

Table C2.3. Sediment Loading Values for 2000 Land Use Conditions.

Land Use Category	*Area (acres)*	*Sediment Load (lbs/year)*	*Unit Area Sediment Load (lbs/acre/yr)*
Hay/Pasture	2,570	43,465	17.03
Cropland	6,926	1,053,201	152.06
Con Forest	296	243	0.82
Mixed Forest	1,908	2,252	1.18
Decid Forest	6,655	10,110	1.52
Unpaved Road	7	3,289	469.86
Transition	1,187	826,324	696.14
Low Intensity Dev	5,909	136,071	23.03
High Intensity Dev	1,804	30,949	
Stream Bank		6,263,576	
Groundwater			
Point Source[1]			
Septic Systems			
Total	27,262	8,369,480	307.00

Table C2.4. Header Information for Tables C2.2 and C2.3.

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

C2.2 LOAD ALLOCATION PROCEDURE FOR SEDIMENT TMDL

The load allocation and reduction procedures were applied to the entire Little Neshaminy watershed. For the sediment TMDL, 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 primary source of stream impairment in the watershed, has increased considerably since 1992. These loads were then used as the basis for establishing the sediment TMDL for the Little Neshaminy watershed.

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.

C2.2.1 TMDL Total Loads

As noted earlier, the TMDL total target load for sediment in the Little Neshaminy watershed is based on the sediment loads obtained using the 1992 land use conditions, and is equal to 7,708,168 lbs/year (see Table C2.2).

C2.2.2 Margin of Safety

The Margin of Safety (MOS) for this analysis is explicit. In this case, ten percent of the TMDL was reserved as the MOS.

MOS (Sediments) *7,708,168 lbs/yr x 0.1 = 770,817 lbs/yr* *(2)*

C2.2.3 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 (Sediments) *7,708,168 lbs/yr - 770,817 lbs/yr = 6,937,351 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.

C2.2.4 Sediment Load Reduction Procedures

The allocation of sediment among contributing sources in the Little Neshaminy sub-watershed was done by reducing each source equally on a percentage basis. Based on the target

WLA of 6,937,351 lbs/year described above, the computed load alocations are those shown in Table C2.5.

Table C2.5. 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	2,726	47,108	43,465	36,032	17
Cropland	7,989	1,286,115	1,053,201	873,004	17
Coniferous Forest	296	240	243	201	17
Mixed Forest	1,911	2,250	2,252	1,867	17
Deciduous Forest	6,918	10,504	10,110	8,381	17
Unpaved Road	7	3,285	3,289	2,727	17
Transitional land	17	3,991	826,324	685,023	17
Low Intensity Devel	5,640	127,814	136,071	112,603	17
High Intensity Devel	1,758	29,731	30,949	25,657	17
Stream Bank Erosion		6,197,130	6,263,576	5,192,105	17
Groundwater					
Point Source					
Septic Systems					
Total	27,262	7,708,168	8,369,480	6,937,351	17

The total allowable sediment load in the Little Neshaminy Creek and its tributaries when all land use/cover sources are considered (as well as the 10% MOS) is 6,937,351 pounds per year. In order for all stream segments to attain their specific uses, the total sediment load should be reduced from 8,369,480 pounds per year by a factor of 17%.

C2.3 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 TMDLs using average annual conditions is protective of the waterbody.

C2.4 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.

C2.5 REASONABLE ASSURANCE OF IMPLEMENTATION

Sediment reductions in the TMDLs are allocated to developed land uses 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 the Little Neshaminy Creek watershed 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 in urban areas will also assist in the reduction of phosphorus originating from transitional and urban land uses and stream bank erosion.

Similarly, implementation of best management practices (BMPs) in the agricultural areas to increase infiltration and decrease sediment loss in these areas should achieve the phosphorus loading reduction goals established in the TMDL discussed later in Section D2.3.7. Substantial reductions in the amount of 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.

C2.6 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.

C3.0 Total Maximum Daily Load (TMDL) Development Plan for Lake Galena

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EXECUTIVE SUMMARY

Lake Galena is located in the upper end of the Neshaminy Creek basin. The lake is approximately 2.33 miles long by 0.25 miles wide, and encompasses an area of about 370 acres. The watershed area that drains into this lake is approximately 9,798 acres in size. In addition to water generated by precipitation within the watershed, Lake Galena also receives substantial inflow of water diverted from the nearby Delaware River for use by the North Penn and North Wales Water Authorities. The watershed contains a mix of land use/cover, including primarily agriculture, woodlands, and residential developments. In particular, this watershed has experienced a significant increase in residential development over the last 5-10 years, which has been identified as an important source of sediment to the lake during this time period. The designated aquatic uses for Lake Galena and North Branch Neshaminy Creek, is Trout Stocking, Migratory Fishes (TS, MF).

The lake was identified on Pennsylvania's current 303(d) list as being impaired by nutrients and suspended solids from various sources, including on-site wastewater, agriculture, urban runoff/storm sewers, and other. Since Pennsylvania does not currently have numeric water quality standards for nutrients or suspended solids, the overall goal of this TMDL is to improve the trophic status of Lake Galena from hyper-eutrophic to mesotrophic. Based on this goal, the water quality target to address the stated impairments has been set at 10 μg/l of chlorophyll-a.

A combined watershed/lake water modeling approach was used to estimate current nutrient and sediment loads to the lake as well as to estimate phosphorus reductions needed to achieve the chlorophyll-a target of 10 μg/l. The land use/cover data layer for the lake watershed was updated using 1999-vintage satellite imagery. The updated layer was used to represent development conditions within the area as well as to estimate the amount of land being developed on a mean annual basis. Based on the modeling, it was estimated that the current annual phosphorus load of 3909 kg/yr (1776.8 lbs/yr) would have to be reduced to 1127 kg/yr (512.3 lbs/yr) in order to achieve the chlorophyll-a target of 10 μg/l. With an additional 10% margin of safety (MOS) factor, this target phosphorus load is further reduced to 1014.3 kg/yr (461.0 lbs/yr). The final load allocations by source are as shown in the table on the following page.

Segments of the North Branch of Neshaminy Creek immediately downstream from Lake Galena (Stream Segment ID# 980210-1123-GLW) were listed also as being impaired by both siltation and water/flow variability caused by an upstream impoundment (i.e., Lake Galena). A TMDL for water/flow variability was not developed in this case because neither the U.S. Environmental Protection Agency (EPA) nor PaDEP currently have water quality criteria for this impairment. Furthermore, quantitative measures for water/flow variability as an "impairment" are not currently available. However, it is assumed for these segments that addressing sediment loads through the use of various BMPs will at the same time reduce water flow variability or alterations within the watershed. With respect to the listed impairment from siltation, it is believed that a separate TMDL for this stream segment is not needed since the reductions for phosphorus specified for the Lake Galena watershed will directly result in sediment reductions in the North Branch as well. It is estimated that the targeted phosphorus reduction will result in approximately a 38% reduction in sediment to the lake as well. It is presumed that this would consequently result in a significant reduction in sediment being delivered to the North Branch.

SOURCE OF P	CURRENT LOAD (kg/yr)[1]	REDUCED LOAD (kg/yr)
Agricultural land[3]	2097	1300[2]
Transitional land (in development)	71	44[2]
Streambank erosion	216	133[2]
Diversion water	1022	-966[5]
Other sources[4]	503[4]	503[4]
TOTAL	3909	1014.0

[1] Based on watershed and lake water quality modeling
[2] Loads reduced by 38% (i.e., current load x 0.62)
[3] Includes 347 kg/yr from groundwater load
[4] Other sources not reduced due to small size of load and/or difficulties in controlling them
[5] Net loss based on diversion water (1022 kg/yr) minus withdrawal water (1988 kg/yr)

C3.0 INTRODUCTION

Lake Galena has been identified on Pennsylvania's current 303(d) list as being impaired by suspended solids and nutrients from various sources (see Table C3.1 below). Lake Galena was initially listed in 1998 as a result of a Clean Lakes Project, and was given a medium priority for TMDL development. Based on this listing, a TMDL for suspended solids and nutrients is being developed.

Table C3.1. Sources and causes of impairment for Lake Galena.

SOURCE	CAUSE
On site Wastewater	Nutrients
Agriculture	Suspended Solids
On site Wastewater	Suspended Solids
Urban Runoff/Storm Sewers	Suspended Solids
Other	Suspended Solids
Agriculture	Nutrients
Urban Runoff/Storm Sewers	Nutrients
Other	Nutrients

C3.0.1 Physical Setting

Lake Galena is located in the upper end of the Neshaminy Creek basin (see Figure C3.1). The lake is approximately 2.33 miles long by 0.25 miles wide, and encompasses an area of about 370 acres. The watershed area that drains into this lake is approximately 9798 acres in size. In addition to water generated by precipitation within the watershed, Lake Galena also receives substantial inflow of water diverted from the nearby Delaware River for water supply use by the North Penn and North Wales Water Authorities. This watershed contains a mix of land use/cover, including primarily agriculture, woodlands, and residential developments. In particular, this watershed has experienced a significant increase in residential development over the last 5-10 years, which has been identified as an important source of sediment to the lake during this time period. In terms of surface geology, the lake and surrounding drainage area is primarily underlain by the Lockatong shale formation. Only one point source (PA0052493) currently exists in the watershed. As shown earlier in Table D1.3, however, the nutrient loads from this source are relatively insignificant. A municipal discharge (PA0031615) that had existed in 1988 is no longer operational.

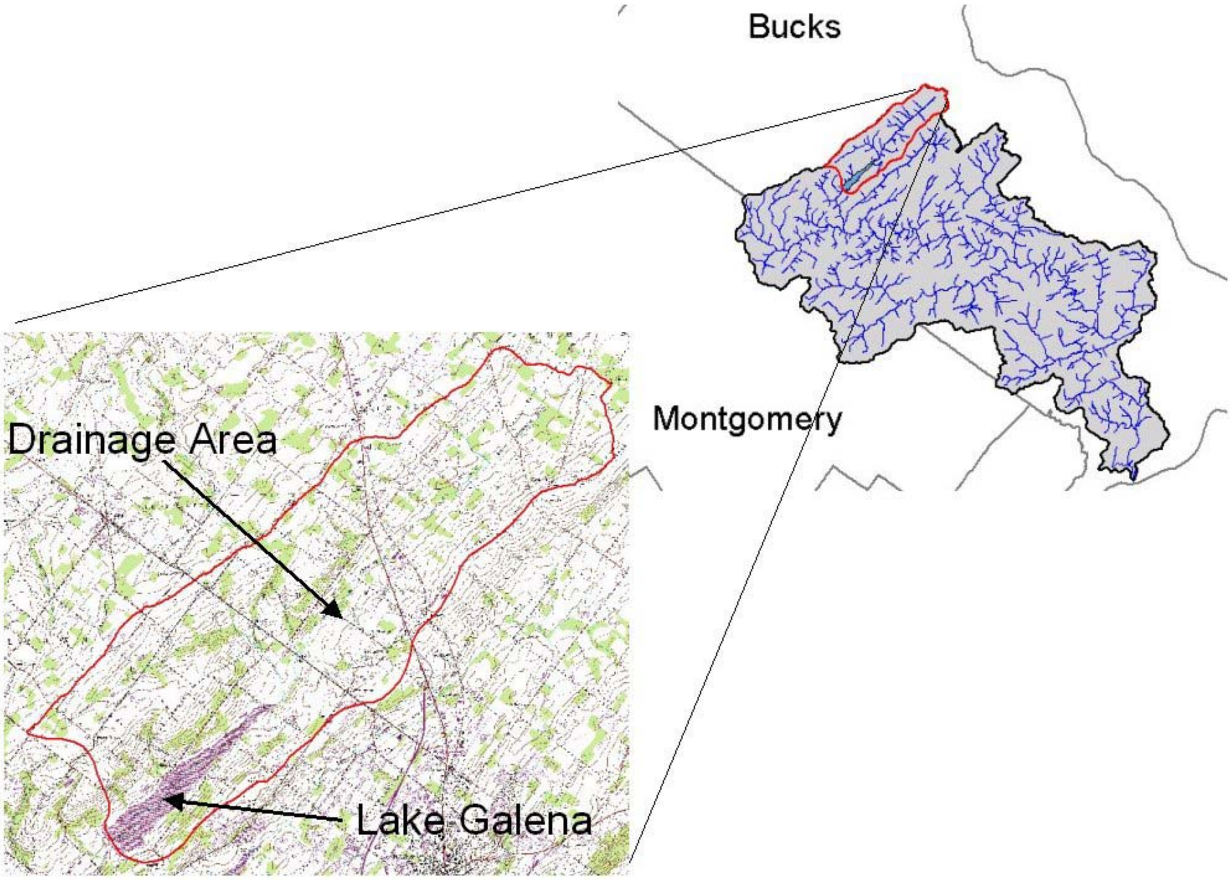


Figure C3.1. Location of Lake Galena.

C3.0.2 Lake Eutrophication

Based on recent studies in Lake Galena, it has been suggested that the lake is undergoing accelerated eutrophication due to the input of nutrients and suspended solids originating from various sources as summarized in Table C3.1. Lake eutrophication is both a natural and culturally-based phenomenon. Natural eutrophication is a slow, largely irreversible process associated with the gradual accumulation of organic matter and sediments in lake basins. Cultural eutrophication is an often rapid, possibly reversible process of nutrient enrichment and high biomass production stimulated by cultural activities causing nutrient transport to lakes (Novotny and Olem, 1994). Lakes are considered to undergo a process of "aging" which can be characterized by the trophic status as *oligotrophic*, *mesotrophic*, or *eutrophic*. Oligotrophic lakes are normally associated with deep lakes which have relatively high levels of dissolved oxygen throughout the year, bottom sediments typically contain small amounts of organic matter, chemical water quality is good, and aquatic populations are both productive and diverse. Mesotrophic lakes are characterized by intermediate levels of biological productivity and diversity, slightly reduced dissolved oxygen levels, and generally have adequate water quality to support designated uses. However, there is a recognition that these lakes are naturally or culturally moving towards a eutrophic state. Lakes which are classified as eutrophic typically exhibit high levels of organic matter, both suspended in the water column and in the upper portions of sediments. Biological productivity is high, often indicated by seasonal algae blooms and excessive plant growth. Dissolved oxygen concentrations are low, and may reach extreme levels during critical periods. In addition, water quality is often poor resulting in violations of the designated uses. The following table illustrates typical water quality values associated with these trophic designations.

Table C3.2. Trophic Status of Lakes

Variable	Oligotrophic	Mezotrophic	Eutrophic
Total P (μg/l)	<10	10-20	>20
Chlorophyll-a (μg/l)	<4	4-10	>10
Secchi disc depth (m)	>4	2-4	<2
Hypolimnetic oxygen (% sat.)	>80	10-80	<10

(Source: Thomann and Mueller, 1987)

C3.0.3 Lake Galena Water Quality

As a result of a past Clean Lakes project funded by the U.S. EPA (F.X. Browne, 1995), various water quality sampling was conducted in Lake Galena. Mean annual values obtained for critical parameters as a result of this sampling for the years 1989-1998 are shown in Table C3.3. The "TSI" values refer to "trophic state index" values calculated by DEP based on the methodology described by Carlson (1977). This index was developed for lakes that are phosphorus limited, which is the case for most lakes in Pennsylvania. Based on observations of several northern temperate lakes (Krenkel and Novotny, 1980), most oligotrophic lakes have TSI values below 40, mezotrophic lakes typically range in value between 35 and 45, and most eutrophic lakes generally have values greater than 45. Hyper-eutrophic lakes, on the other hand, can have TSI values above 60. Based on these values (as well as the ones shown in Table C3.2), it can be seen that Lake Galena appears to be in an advanced state of eutrophication since the TSI values in Table C3.3 range from 60.44 to 73.20. This situation is likely exacerbated by the nutrients, organic solids, and nutrient-enriched sediments entering the lake from the various sources summarized in Table C3.1.

C3.0.4 Water Quality Standards

Water quality standards are typically developed to control quantities of various pollutants that may enter water bodies in order to maintain healthy conditions and usually consist of three inter-related components: 1) designated and existing uses, 2) narrative and/or numerical water quality criteria necessary to support those uses, and 3) an anti-degradation statement. Furthermore, water quality standards serve the dual purposes of establishing the water quality goals for a specific waterbody and serve as the regulatory basis for the establishment of water quality-based treatment controls and strategies beyond the technology-based levels of treatment required by section 301(b) and 306 of the Act (USEPA, 1991).

Table C3.3. Selected mean annual water quality values for Lake Galena.

Parameter	Measured/Calculated Value
Chlorophyll-a (μg/l)	28.99
Secchi disk depth (m)	0.97
Total nitrogen (μg/l)	1388.6
Organic nitrogen (μg/l)	774.3
Total phosphorus (μg/l)	120.1
Ortho-phosphorus (μg/l)	33.5
TSI-P	73.20
TSI-Chlorophyll-a	63.63
TSI-Secchi disk	60.44

According to Pennsylvania Code, Title 25, Chapter 93, Water Quality Standards, Section 93.4, all surface waters in the state shall be protected for the following uses: warm water fishes, potable water supply, industrial water supply, livestock water supply, wildlife water supply, irrigation, boating, fishing, water contact sports, and aesthetics. Lake Galena, and the North Branch of Neshaminy Creek that flows into it, have been designated for Trout Stocking, Migratory Fishes (TS,MF).

Pennsylvania does not currently have specific numeric water quality criteria for suspended solids or nutrients to support these uses. However, Pennsylvania does have general water quality criteria that state in Section 93.6 that: *a) Water may not contain substances attributable to point or nonpoint source discharges in concentration or amounts sufficient to be inimical or harmful to the water uses to be protected or to human, animal, plant or aquatic life; and b) In addition to other substances listed within or addressed by this chapter, specific substances to be controlled include, but are not limited to, floating materials, oil, grease, scum and substances which produce color, tastes, orders, turbidity or settle to form deposits.* These general water quality criteria may be interpreted to identify an acceptable water quality endpoint. Pennsylvania has numeric water quality criteria for total dissolved solids, however, these criteria only apply to public water supplies.

C3.0.5 Numeric Water Quality Target

In order to develop a given TMDL, a water quality indicator and numeric water quality target must be specified. As mentioned, Pennsylvania does not currently have numeric water quality standards for nutrients or suspended solids. Therefore, the overall goal of this TMDL will be to improve the trophic status of Lake Galena from hyper-eutrophic to mesotrophic. As described above, the current hyper-eutrophic conditions are due to excessive nutrient input to the lake (particularly phosphorus, since this is the limiting nutrient in this case). In this watershed, most of the phosphorus originates from nonpoint source runoff in both dissolved and particulate (i.e., sediment-attached) forms. This runoff results in increased concentration of suspended solids in the lake which is comprised of both organic organisms as well as suspended sediment. It is expected, therefore, that reductions in both dissolved and sediment-borne forms of phosphorus will result in decreased nutrient and suspended solids in Lake Galena. This, in fact, was one of the conclusions drawn from the earlier Clean Lakes study conducted for Lake Galena and its surrounding watershed (F.X. Browne, 1995).

According to the trophic state index values given in Table C3.2, there are 4 parameters used to relate water quality with trophic state. In this case, *chlorophyll-a* will be used as the numeric water quality target. Chlorophyll-a is easy to measure, is a valuable surrogate for algal biomass, and is desirable as a water quality target because alga are either the direct (nuisance algal blooms) or indirect (high/low dissolved, pH, and high turbidity) cause of most problems related to excessive enrichment (US EPA, 1999(a)). Based on the goal of improving the trophic status of Lake Galena from hyper-eutrophic to mesotrophic, the water quality target to address nutrient impairments has been set at 10 μg/l chlorophyll-a. More specifically, as described in the next section, estimates of phosphorus reductions needed to achieve this goal are made via the combined use of a watershed model (AVGWLF) and a lake water quality model (BATHTUB).

C3.1 TMDL ASSESSMENT METHODOLOGY

C3.1.1 Overview

A combined watershed modeling/lake water quality modeling approach was used to conduct the TMDL assessment for Lake Galena. The lake model is BATHTUB, which performs steady-state water and nutrient balance calculations in a spatially segmented hydraulic network that accounts for advective and diffusive transport, and nutrient sedimentation (Walker, 1996). BATHTUB is used to simulate the fate and transport of nutrients and water quality conditions and responses to nutrient loads into the lake. BATHTUB has been cited as an effective tool for lake and reservoir water quality assessment and management, particularly where data are limited (US EPA, 1999). In order to simulate water quality conditions, BATHTUB requires as input information on various lake characteristics such as length, width, mean depth, and nutrient loads from various sources in the surrounding watershed. Basic physical and hydrologic information was obtained via a combination of field work, reports, GIS data sets, and topographic maps. Information on nutrient loading to the lake from the surrounding area was derived using the AVGWLF watershed modeling application (see background discussions in Section B). Subsequent to setting up the two models, calibration was performed using actual lake water quality sampling data obtained as a result of a prior EPA-funded Clean Lakes project (F.X. Browne, Inc., 1995). This calibration was needed in order to accurately estimate phosphorus reductions required to achieve the chlorophyll-a target goal of 10 μg/l.

For the purposes of this TMDL assessment, mean annual nutrient loads to the lake for the period 1988-1998 were estimated. These loads were then used within BATHTUB to evaluate current water quality/trophic conditions. Once current conditions had been established and compared with existing lake water quality sampling measurements, the BATHTUB model was then used as a "diagnostic" tool in order to estimate the phosphorus load reductions required to achieve the chlorophyll-a target of 10 μg/l.

C3.1.2 Watershed Modeling

As outlined above, AVGWLF was used to derive nutrient load information for use as input to the BATHTUB lake model. Simulations were performed for the period 1988-1998 to coincide with the time period for which existing weather and lake water sampling data were available. When using AVGWLF, the "default" GIS data sets that come with this application are typically used (see Section B1.2). This means that for most applications, the "satellite-derived", *Pamrlc* land use/cover data set is generally utilized (see Table B1). However, in areas where land development is considered to be a possible factor with respect to water quality degradation (as is the case in this watershed), this particular data layer may not be adequate for comprehensive problem assessment since the satellite images used to create this data layer were primarily from the year 1992. Consequently, to better reflect current land use/cover conditions in the watershed, the existing *Pamrlc* was updated using more recent satellite data available for the area (in this instance, 1999-vintage SPOT satellite images [see Section C2.0.1 for related discussion on this image data]). Figure C3.2 shows the default land use/cover map used within AVGWLF and the map that was updated for this particular analysis.

As can be seen from Figure C3.2, the amount of developed land in the watershed (primarily low-density and high-density residential land) has changed significantly since 1992. In fact, between 1992 and 1999, the amount of developed land had increased from approximately 75 hectares (185 acres) to approximately 788 hectares (1946 acres). This amounts to an average of about 100 hectares (247 acres) of new development per year during the 7-year time period reflected by the two land use/cover layers. For GWLF modeling purposes, the newer land use/cover layer was used to represent current development conditions in the watershed. Additionally, it was assumed that about 100 hectares (247 acres) of land per year is "under development". Within GWLF, this amount was included in the "transition" category to reflect land that is generally without vegetative cover and subject to significant surface erosion during precipitation events. As described previously, sediment transported via erosion can be an important source of phosphorus in the lake.

Screen captures of the transport- and nutrient-related input data for the final GWLF model run are shown in Figures C3.3 and C3.4. The resulting mean annual hydrology and loading output from this final run is shown is Figures C3.5 and C3.6. The most important results presented in these figures are those given in the "Totals" columns highlighted in each case in light blue at the bottom. More specifically, these values were used to estimate mean annual inputs to Lake Galena with respect to water flow and nutrient loads as described in the next section.

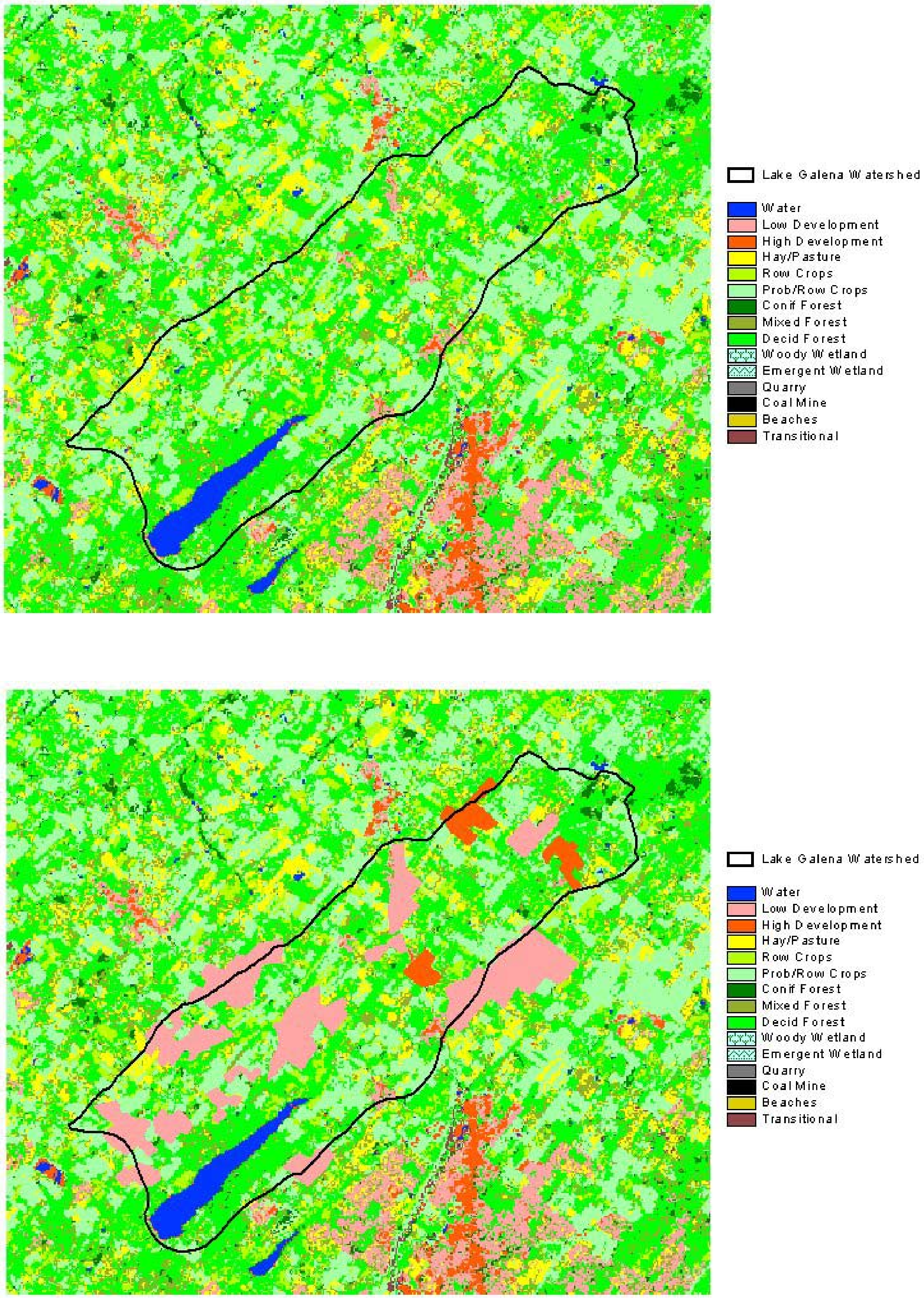
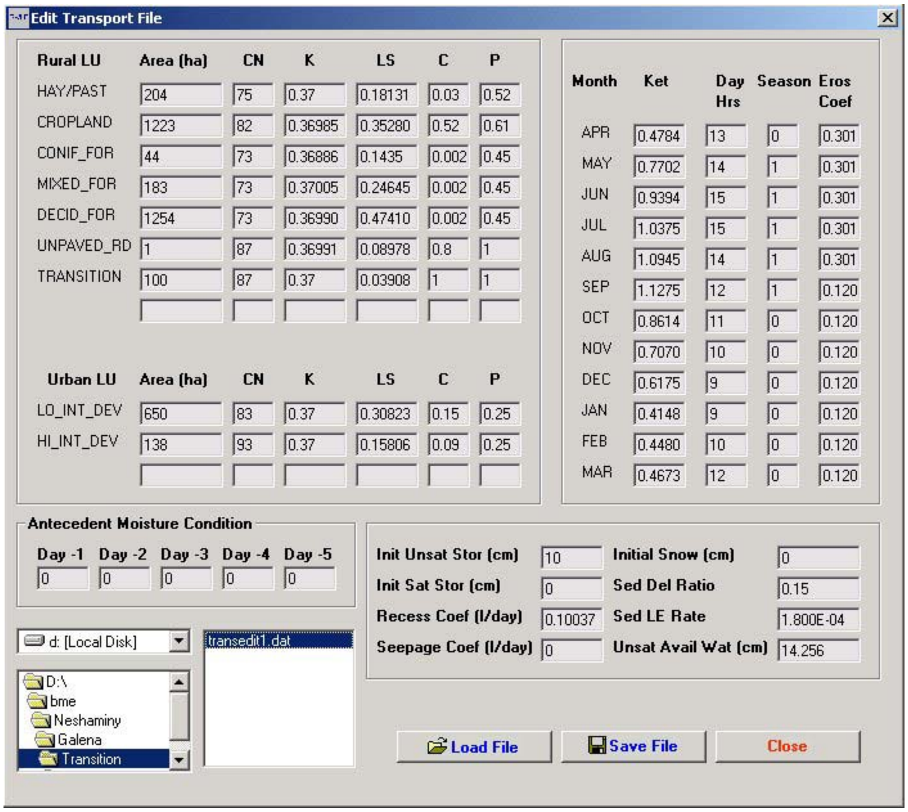


Figure C3.2. Land use/cover ca. 1992 (top) and 1999 (bottom) within the Lake Galena watershed.



Rural LU	Area (ha)	CN	K	LS	C	P
HAY/PAST	204	75	0.37	0.18131	0.03	0.52
CROPLAND	1223	82	0.36985	0.35280	0.52	0.61
CONIF_FOR	44	73	0.36886	0.1435	0.002	0.45
MIXED_FOR	183	73	0.37005	0.24645	0.002	0.45
DECID_FOR	1254	73	0.36990	0.47410	0.002	0.45
UNPAVED_RD	1	87	0.36991	0.08978	0.8	1
TRANSITION	100	87	0.37	0.03908	1	1

Urban LU	Area (ha)	CN	K	LS	C	P
LO_INT_DEV	650	83	0.37	0.30823	0.15	0.25
HI_INT_DEV	138	93	0.37	0.15806	0.09	0.25

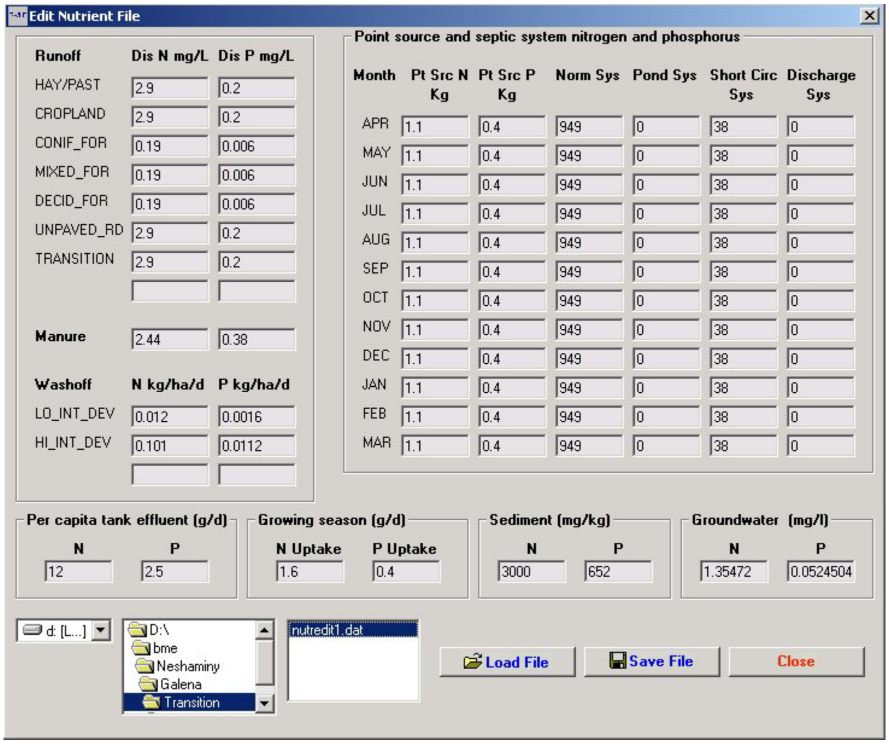
Month	Ket	Day Hrs	Season	Eros Coef
APR	0.4784	13	0	0.301
MAY	0.7702	14	1	0.301
JUN	0.9394	15	1	0.301
JUL	1.0375	15	1	0.301
AUG	1.0945	14	1	0.301
SEP	1.1275	12	1	0.120
OCT	0.8614	11	0	0.120
NOV	0.7070	10	0	0.120
DEC	0.6175	9	0	0.120
JAN	0.4148	9	0	0.120
FEB	0.4480	10	0	0.120
MAR	0.4673	12	0	0.120

Antecedent Moisture Condition

Day -1	Day -2	Day -3	Day -4	Day -5
0	0	0	0	0

Init Unsat Stor (cm)	10	Initial Snow (cm)	0
Init Sat Stor (cm)	0	Sed Del Ratio	0.15
Recess Coef (l/day)	0.10037	Sed LE Rate	1.800E-04
Seepage Coef (l/day)	0	Unsat Avail Wat (cm)	14.256

Figure C3.3. GWLF transport file for Lake Galena watershed load estimation.



Runoff	Dis N mg/L	Dis P mg/L
HAY/PAST	2.9	0.2
CROPLAND	2.9	0.2
CONIF_FOR	0.19	0.006
MIXED_FOR	0.19	0.006
DECID_FOR	0.19	0.006
UNPAVED_RD	2.9	0.2
TRANSITION	2.9	0.2
Manure	2.44	0.38

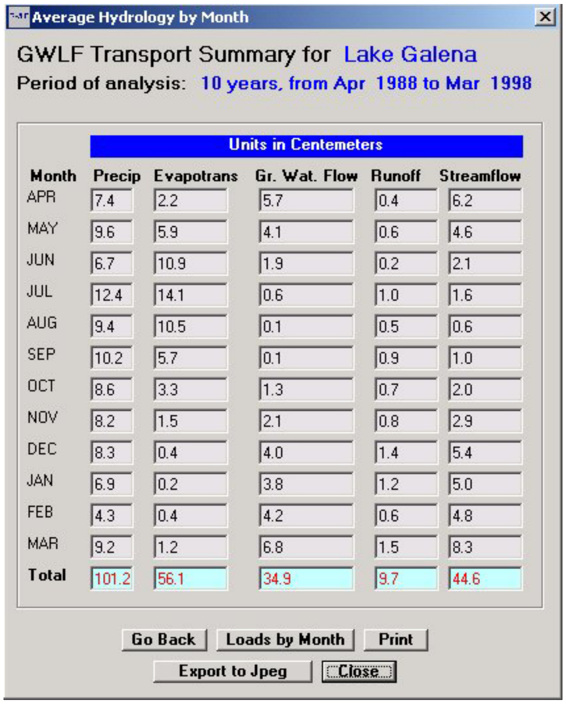
Washoff	N kg/ha/d	P kg/ha/d
LO_INT_DEV	0.012	0.0016
HI_INT_DEV	0.101	0.0112

Point source and septic system nitrogen and phosphorus

Month	Pt Src N Kg	Pt Src P Kg	Norm Sys	Pond Sys	Short Circ Sys	Discharge Sys
APR	1.1	0.4	949	0	38	0
MAY	1.1	0.4	949	0	38	0
JUN	1.1	0.4	949	0	38	0
JUL	1.1	0.4	949	0	38	0
AUG	1.1	0.4	949	0	38	0
SEP	1.1	0.4	949	0	38	0
OCT	1.1	0.4	949	0	38	0
NOV	1.1	0.4	949	0	38	0
DEC	1.1	0.4	949	0	38	0
JAN	1.1	0.4	949	0	38	0
FEB	1.1	0.4	949	0	38	0
MAR	1.1	0.4	949	0	38	0

Per capita tank effluent (g/d)		Growing season (g/d)		Sediment (mg/kg)		Groundwater (mg/l)	
N	P	N Uptake	P Uptake	N	P	N	P
12	2.5	1.6	0.4	3000	652	1.35472	0.0524504

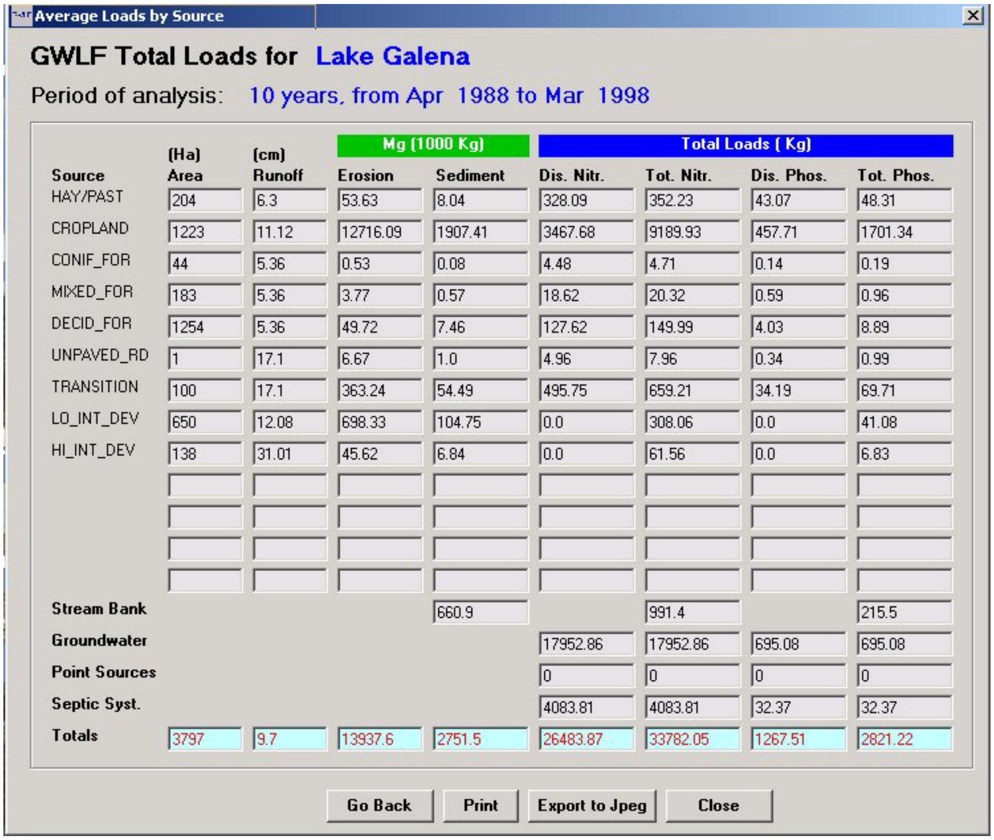
Figure C3.4. GWLF nutrient file for Lake Galena watershed load estimation.



GWLF Transport Summary for Lake Galena
Period of analysis: 10 years, from Apr 1988 to Mar 1998

	Units in Centemeters				
Month	**Precip**	**Evapotrans**	**Gr. Wat. Flow**	**Runoff**	**Streamflow**
APR	7.4	2.2	5.7	0.4	6.2
MAY	9.6	5.9	4.1	0.6	4.6
JUN	6.7	10.9	1.9	0.2	2.1
JUL	12.4	14.1	0.6	1.0	1.6
AUG	9.4	10.5	0.1	0.5	0.6
SEP	10.2	5.7	0.1	0.9	1.0
OCT	8.6	3.3	1.3	0.7	2.0
NOV	8.2	1.5	2.1	0.8	2.9
DEC	8.3	0.4	4.0	1.4	5.4
JAN	6.9	0.2	3.8	1.2	5.0
FEB	4.3	0.4	4.2	0.6	4.8
MAR	9.2	1.2	6.8	1.5	8.3
Total	101.2	56.1	34.9	9.7	44.6

Figure C3.5. Mean annual hydrology reported by GWLF.



GWLF Total Loads for Lake Galena
Period of analysis: 10 years, from Apr 1988 to Mar 1998

			Mg (1000 Kg)		Total Loads (Kg)			
Source	**(Ha) Area**	**(cm) Runoff**	**Erosion**	**Sediment**	**Dis. Nitr.**	**Tot. Nitr.**	**Dis. Phos.**	**Tot. Phos.**
HAY/PAST	204	6.3	53.63	8.04	328.09	352.23	43.07	48.31
CROPLAND	1223	11.12	12716.09	1907.41	3467.68	9189.93	457.71	1701.34
CONIF_FOR	44	5.36	0.53	0.08	4.48	4.71	0.14	0.19
MIXED_FOR	183	5.36	3.77	0.57	18.62	20.32	0.59	0.96
DECID_FOR	1254	5.36	49.72	7.46	127.62	149.99	4.03	8.89
UNPAVED_RD	1	17.1	6.67	1.0	4.96	7.96	0.34	0.99
TRANSITION	100	17.1	363.24	54.49	495.75	659.21	34.19	69.71
LO_INT_DEV	650	12.08	698.33	104.75	0.0	308.06	0.0	41.08
HI_INT_DEV	138	31.01	45.62	6.84	0.0	61.56	0.0	6.83
Stream Bank				660.9		991.4		215.5
Groundwater					17952.86	17952.86	695.08	695.08
Point Sources					0	0	0	0
Septic Syst.					4083.81	4083.81	32.37	32.37
Totals	3797	9.7	13937.6	2751.5	26483.87	33782.05	1267.51	2821.22

Figure C3.6. Mean annual load calculations by GWLF.

C3.1.3 Lake Water Quality Modeling

Using descriptive information about the lake and surrounding drainage area, as well as output from AVGWLF, a BATHTUB model was set up for Lake Galena for the purpose of simulating current water quality and trophic conditions. For the purposes of this TMDL assessment, mean annual nutrient loadings were simulated using AVGWLF output and DEP lake sampling data for the period 1988-1998. After initial model development, the sampling data were used to "fine-tune" various input parameters and sub-model selections within BATHTUB during the calibration process. Once calibrated, as described in a later section, BATHTUB could then be used to estimate nutrient (specifically phosphorus) load reductions needed in order to achieve TMDL target loads.

Given the relatively small size and simple shape of Lake Galena in comparison to lakes and reservoirs typically modeled with BATHTUB, the lake was treated as a single "segment" (i.e., pool) within the model. Similarly, water inflow and nutrient loads from the surrounding drainage area was treated as though they originated from one "tributary" (i.e., source) in BATHTUB. The model-required flow and nutrient concentration information for this particular source was derived from the AVGWLF output as described above. Also, as mentioned previously, a significant amount of water is drawn from the nearby Delaware River and diverted to Lake Galena for use local water suppliers. Based on information from DEP, this inflow amounts to an annual volume of about 3600 million gallons per year, which is a little less than half of the water entering the lake annually. Within BATHTUB, this source was identified as an additional tributary to the lake. Unfortunately, information on current nutrient concentrations was not available from DEP for this diversion. Consequently, water quality data obtained at a DEP water quality monitoring station (WQN101) located on the Delaware River downstream from the water supply intake for Lake Galena was used to estimate nitrogen and phosphorus concentrations for this inflow. Model parameter data for the lake and its surrounding drainage area are summarized in Table C3.4. Flow and concentration data for the two sources of input to Lake Galena is given in Table C3.5.

In addition to the input summarized in the tables above, executing BATHTUB also requires that decisions be made on the use of various nutrient balance, sedimentation, and eutrophication response sub-models. Such decisions are routinely made as part of the calibration process where the primary objective is to simulate processes in a way that achieves optimal matches between values for observed lake water quality parameters and estimated values based on compiled input data. For Lake Galena, optimal results were achieved using the sub-models given in Table C3.6.

The results from the final BATHTUB model run for key model parameters are shown in Table C3.7. The matches between simulated and observed mean annual water quality conditions were considered to be quite good, and based on these results, it was felt that these conditions were being simulated well enough to allow estimation of phosphorus reductions needed to achieve the chlorophyll-a TMDL target. Therefore, subsequent to calibrating the lake water quality model, additional model runs were made to quantify the phosphorus reductions to the lake needed in order to achieve TMDL objectives with respect to chlorophyll-a levels. Specifically, phosphorus loads to the lake as represented by various model sources (watershed, diversion, and atmosphere) were

Table C3.4. Lake and watershed data.

PARAMETER	VALUE
Lake area[1]	370 acres (1.5 km^2)
Lake length[1]	2.33 miles (3.74 km)
Lake width[1]	0.25 miles (0.4 km)
Mean depth of lake[2]	15 feet (4.6 m)
Atmospheric N loading to lake[3]	2698 kg/km^2
Atmospheric P loading to lake[3]	44 kg/km^2
Mean annual Total P concentration of lake[4]	120.1 ppb
Mean annual Ortho-P concentration of lake[4]	33.5 ppb
Mean annual Total N concentration of lake[4]	1388.6 ppb
Mean annual Organic N concentration of lake[4]	774.3 ppb
Mean annual Chlorophyll-a concentration of lake[4]	28.99 ppb
Mean annual Secchi disk depth of lake[4]	0.97 m

[1] Topographic map, GIS data, and Clean Lakes study (DEP/F.X. Browne)
[2] Clean Lakes study (DEP/F.X. Browne)
[3] Nizeyimana et al. (1997)
[4] DEP sample data

Table C3.5. Mean annual source flows and nutrient loads.

PARAMETER	WATERSHED[1]	DIVERSION
Flow	12.76 MGD (17.64 hm^3/yr)	9.86 MGD (13.63 hm^3/yr)[2]
Total N concentration	1.7421 mg/l (1742.1 ppb)	0.98 mg/l (980 ppb)[3]
Inorganic N concentration	1.5219 mg/l (15219 ppb)	0.85 mg/l (850 ppb)[3]
Total P concentration	0.1599 mg/l (159.9 ppb)	0.075 mg/l (75.0 ppb)[3]
Ortho-P concentration	0.0719 mg/l (71.9 ppb)	0.034 mg/l (34 ppb)[3]

[1] Derived via AVGWLF-based watershed modeling
[2] From DEP data
[3] Derived from Delaware River water quality monitoring station data (WQ101)

Table C3.6. Sub-models used within BATHTUB for Lake Galena.

MODEL OPTION	SUB-MODEL USED
Phosphorus balance/sedimentation	First-order settling velocity
Nitrogen balance/sedimentation	First-order settling velocity
Mean chlorophyll-a	P, Linear
Secchi depth	Secchi vs. Chl-a and Turbidity

Table C3.7. Final lake model simulation results for Lake Galena.

VARIABLE	OBSERVED VALUE	ESTIMATED VALUE
Total P (mg/m^3)	120.10	117.14
Total N (mg/m^3)	1388.60	1442.46
Chlorophyll-a (mg/m^3)	28.99	32.80
Secchi depth (m)	0.97	0.89
Organic N (mg/m^3)	774.30	927.86
TP – Ortho-P (mg/m^3)	86.60	61.54
Turbidity (1/m)	0.31	0.31
Carlson TSI-P	73.20	72.84
Carlson TSI-Chla	63.63	64.84
Carlson TSI-Secchi	60.44	61.71

iteratively decreased until a simulated chlorophyll-a concentration of 10 µg/l was reached. Based on the calibration, the mean annual total P loads from these sources were 2821, 1022, and 66 kg/yr, respectively, for a total of 3909 kg/yr. Upon re-running the lake model as described above, it was found that a mean annual chlorophyll-a concentration of 10 µg/l could be achieved if the annual P load was reduced to 1127 kg/yr.

C3.1.4 Load Allocation

Based on the analyses described above, the approximate mean annual load of 3909 kg of phosphorus that enters the lake comes primarily from the sources shown in Table C3.8. The specific pathways by which phosphorus is transported from these sources varies considerably, and because of this, opportunities for controlling the movement and retention of this nutrient will vary considerably as well. From agricultural land, phosphorus originates principally from soil erosion and application of manure and/or fertilizers. Phosphorus is lost from wooded areas in surface water

Table C3.8. Mean annual P source loads for Lake Galena.

SOURCE	P (kg/yr)
Agricultural land	1750
Wooded land	10
Transitional/unpaved land	71
Developed land	48
Stream bank erosion	216
Groundwater	695
Septic systems	32
Water supply diversion	1022
Atmospheric deposition	66
TOTAL	3909

runoff in dissolved and particulate organic forms. From transitional and unpaved surfaces, it is primarily delivered via sediment during erosion events. In developed areas (in this case, residential areas in the watershed), phosphorus originates primarily from applied fertilizers and eroded organic matter. In the case of stream bank erosion, phosphorus found in the inherent parent material is moved as the banks are eroded due to increased volumes during storm events. As demonstrated by abundant research (e.g., Novotny and Olem, 1994; and Nelson and Booth, 2002), stream bank erosion is a significant problem in fast-developing watersheds due to increased surface water runoff resulting from reduced surface infiltration. Although the quantities are small in comparison to nitrates, some dissolved phosphorus is also transported from septic systems. With respect to groundwater, there is typically a small "background" concentration owing to various natural sources; however, it is true that this concentration can increase substantially in agricultural areas. In the Lake Galena watershed, the estimated groundwater P concentration is about 0.052 mg/l (see Figure C3.4), which is about twice the concentration found in more "natural" settings around Pennsylvania (Reese and Lee, 1998). Consequently, it is very likely that about half of the estimated mean annual groundwater P load (or about 347 kg/yr) is actually from agricultural sources (i.e., leached in dissolved form from the surface). Finally, as discussed earlier, about 1022 kg/yr of P is contributed by the water supply diversion, and about 66 kg/yr is deposited from the atmosphere.

As stated earlier, the lake model simulation showed that the chlorophyll-a target of 10 μg/l could be reached if the mean annual P load were reduced to about 1127 kg/yr. If this load were reduced again by a 10% margin-of-safety factor, a new target load of 1014 kg/yr would be required for meeting lake water quality objectives. This means that the mean annual P load to Lake Galena would have to be reduced by 2895 kg/yr (3903 – 1014 = 2895), which at first glance appears to be a rather daunting task. However, as mentioned earlier, Lake Galena is presently being used as a source of drinking water by the North Penn and North Wales Water

Authorities. As such, about 12 MGD is currently being withdrawn from the lake for this purpose. This amount is equivalent to about 45,378,000 liters per year. If it is assumed that the phosphorus concentration of the water being withdrawn is the same as the mean annual total P concentration of the lake (or 0.12 mg/l as shown in Table C3.4), then about 1988 kg/year of P is already being removed from the lake on a yearly basis [3909 kg/yr – ((45,378,000 l/yr * 0.12 mg/l) / 1,000,000 mg/kg) * 365 days/yr = 1988 kg/yr]. Consequently, this leaves about 907 kg/yr of P that still has to be removed from the annual load [(3909 – 1988) – 1014 = 907].

Based on the magnitude of the contributed P load and potential opportunities for load reduction, the most appropriate sources to consider controlling are agricultural land, transitional land and stream bank erosion. It is not reasonable to consider reducing the load in the diversion water since this input is already having a dilutional effect on the concentration of P in the lake. As can be seen in Tables C3.4 and C3.5, the P concentration of the diversion water is about 0.075 mg/l, whereas the concentrations of P in surface runoff entering the lake and the lake water itself are about 0.16 mg/l and 0.12 mg/l, respectively. When combined, the phosphorus loads from agricultural land, transitional land, and stream bank erosion amount to about 1921 kg/yr. If these loads are reduced equally by about 38%, then the target load of 1014 kg/yr could be met as shown in Table C3.9.

Table C3.9. Load allocations needed to meet target P load of 1014 kg/yr.

SOURCE OF P	**CURRENT LOAD (kg/yr)[1]**	**REDUCED LOAD (kg/yr)**
Agricultural land[3]	2097	1300[2]
Transitional land (in development)	71	44[2]
Streambank erosion	216	133[2]
Diversion water	1022	-966[5]
Other sources[4]	503[4]	503[4]
TOTAL	3909	1014

[1] Based on watershed and lake water quality modeling
[2] Loads reduced by 38% (i.e., current load x 0.62)
[3] Includes 347 kg/yr from groundwater load
[4] Other sources not reduced due to small size of load and/or difficulties in controlling them
[5] Net loss based on diversion water (1022 kg/yr) minus withdrawal water (1988 kg/yr)

C3.2 NORTH BRANCH NESHAMINY CREEK

Segments of the North Branch of Neshaminy Creek immediately downstream from Lake Galena (Stream Segment ID# 980210-1123-GLW) were listed as being impaired by both siltation and water/flow variability caused by an upstream impoundment. This impoundment is, in fact, Lake Galena as discussed above (see Figure C3.7). A TMDL for water/flow variability was not developed in this case because neither the U.S. Environmental Protection Agency (EPA) nor PaDEP currently have water quality criteria for this impairment. Furthermore, quantitative measures for water/flow variability as an "impairment" are not currently available. However, it is assumed for these segments that addressing sediment loads through the use of various BMPs as discussed below in Section C.5 will at the same time reduce water flow variability or alterations within the watershed.

With respect to the listed impairment from siltation, it is believed that a separate TMDL for this stream segment is not needed since the reductions for phosphorus specified for the Lake Galena watershed will directly result in sediment reductions in the North Branch as well. As shown in Table C3.9, the recommended TMDL will require a 38% reduction in phosphorus [1 – ((1300+44+133) / (2097+71+216)) = 0.38] from controllable nonpoint sources in order to meet the target water quality goal (including the 10% margin of safety). As discussed above, a significant portion of the phosphorus contributed to the lake is delivered as sediment-attached P, primarily from agricultural land, transitional land (i.e., land under construction), and streambank erosion. It can therefore be surmised that since 100% of the controllable phosphorus load is being contributed by these three sources, that a 38% reduction in P would also result in approximately a 38% reduction in sediment to the lake. This presumably would result in a similar reduction in sediment being delivered to the North Branch as well.

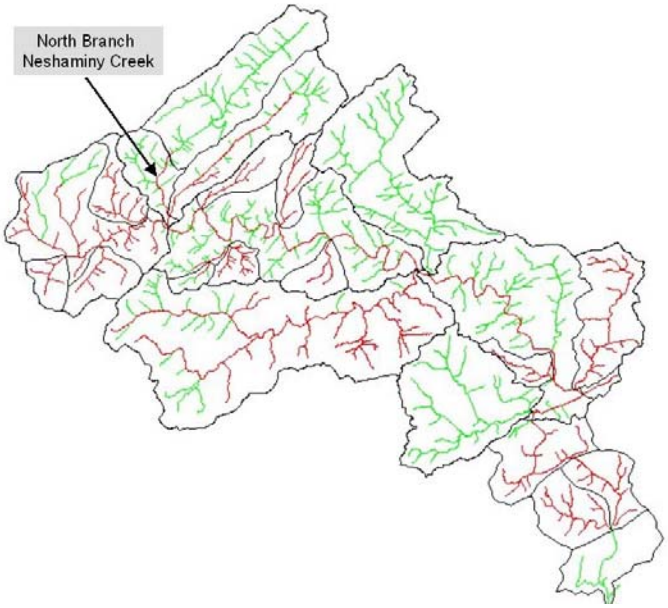


Figure C3.7. Location of North Branch Neshaminy Creek.

C3.3 CONSIDERATION OF CRITICAL CONDITIONS

The AVGWLF model used for mean annual load estimation 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. In this case, a 10-year simulation period reflecting actual data for the period 1988-1998 were used to account for normal year-to year fluctuations in precipitation and temperature.

C3.4 CONSIDERATION OF SEASONAL VARIATIONS

The continuous watershed 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.

C3.5 REASONABLE ASSURANCE OF IMPLEMENTATION

In this TMDL assessment, controllable dissolved and sediment-borne phosphorus loads have been attributed to agricultural land, transitional land (i.e., land in development), and streambank erosion. With respect to agricultural land, various best management practices (BMPs) are available that can reduce phosphorus loads from such areas. Combinations of BMPs such as conservation tillage, crop residue management, field buffers, and nutrient management have been shown to achieve high levels of phosphorus management if applied consistently and conscientiously (Ritter and Shirmohammadi, 2001). In transitional areas, phosphorus attached to sediment can be controlled by requiring the implementation of rigorous erosion and sediment (E&S) control plans by land developers and monitoring such plans for adherence.

Similarly, sediment losses attributed to streambank erosion can be reduced through implementation of best management practices (BMPs) in developed areas to increase infiltration and detain sediment. Substantial reductions in the amount of sediment reaching the lake can be made through the installation of drainage controls such as detention ponds, sediment ponds, constructed wetlands, infiltration pits, dikes and ditches. In fact, the implementation of such BMPs in this particular watershed will likely occur 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 the Little Neshaminy Creek watershed will be affected by this policy, which has been included in Appendix E. In this instance, implementation of BMPs aimed at sediment reduction will also assist in the reduction of phosphorus originating from transitional land uses and stream bank erosion.

C3.6 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.

C4.0 Total Maximum Daily Load (TMDL) Development Plan for Pine Run Watershed

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EXECUTIVE SUMMARY

The Pine Run watershed in Bucks County is approximately12.0 square miles in size. Pine Run is a tributary of North Branch Neshaminy Creek. The protected uses of the watershed are water supply, recreation, and aquatic life. Its aquatic use is trout stocking and migratory fishes.

Total Maximum Daily Loads (TMDLs) apply to about 7.1 miles of the main steam of Pine Run (Stream Segment ID#s 980210-1240-GLW and 980211-1241-GLW) from its mouth going upstream, and 1.3 miles of an unnamed tributary (Stream Segment ID# 980210-1242-GLW) located at about 1/5 mile north of the town of New Britain. They were developed to address the impairments noted on Pennsylvania's 2002 Clean Water act Section 303(d) Lists. The impairments are primarily caused by sediment loads from land development in the watershed. Consequently, the TMDL focuses on control of sediments. Excessive algae growth, also listed as a cause of impairment due to an upstream impoundment, was not explicitly addressed because it is believed that the implementation of BMPs in the urban land use areas (both developed and developing) to reduce sediment in runoff would also decrease build-up of sediments in the upstream impoundment, and subsequently a decrease in phosphorus.

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 sediments in the impaired segments of the Pine Run watershed. The approach is based on the comparison of simulated sediment loads at two time periods: Year 1992 when the stream was still attaining its designated use, and Year 2000 when it was found to be impaired. Siltation, the cause of impairment in Pine Run, 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 Pine Run was 2,160,265 pounds per year. It is assumed that Pine Run will support its aquatic life uses when this value is met. The sediment TMDL for Pine Run is allocated as shown in the table below.

Summary of TMDL for Pine Run Watershed (lbs/yr)

Pollutant	Source	TMDL	MOS	WLA	LA	LNR	ALA
Sediment	Upland and stream bank erosion	2,160,265	216,026	1,944,239	-	-	-

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 8.4 miles of the main stem of Pine Run and its unnamed tributary. The TMDL establishes a reduction for total sediment loading of 52% from the current annual loading of 4,089,625 pounds. This reduction includes the 10% MOS.

C4.0 INTRODUCTION

C4.0.1 Watershed Description

The following discussion provides information on the physical characteristics of Pine Run and its watershed including its location, land use distributions, and geology. Pine Run watershed is located entirely in Bucks county and is in the Piedmont physiographic province. It covers an area of approximately 12.0 square miles. Pine Run drains into the main stem of North Branch of Neshaminy Creek in the town of Chalfont. The watershed is bounded to the south by Pennsylvania Route 202, and to the east by Route 611. It can also be accessed from Norristown via Route 202 or from Doylestown via Route 611. Figure C4.1 shows the watershed boundary, its location, and the state of water quality of stream segments as reported from the 2002 303(d) List. The protected uses of the watershed are 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 main stem of Pine Run and its unnamed tributary is trout stocking and migratory fishes.

The current land use distribution in Pine Run watershed was developed by updating the National Land Cover Data (NLCD) (Vogelmann et al., 1998) using a more recent satellite imagery; the 10 m-colorized SPOT (System Probatoire pour l'Observation de la Terre). The NLCD development 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://www.pasda.psu.edu) at no charge. The primary land uses in the Pine Run watershed are agriculture (37%) and forested land (37%), followed by developed land (26%). It is important to note that development in the watershed more than doubled from 1992 to 2000. It increased from 340 to 768 hectares (126%) during the 8-year period.

The surficial geology of Pine Run watershed consists primarily of sandstone of the Stockton formation. This formation is the best source for water supply wells in the area although yields vary considerably. 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 K factor. Watershed characteristics are summarized in Table C4.1.

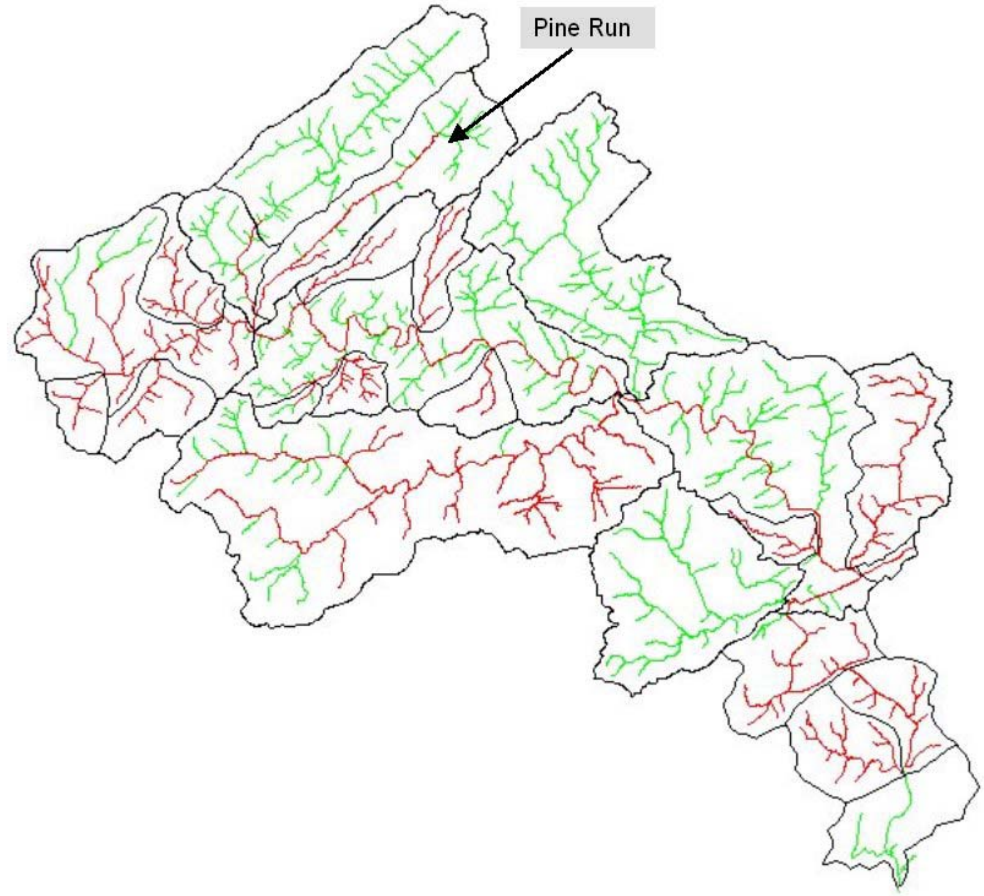

Figure C4.1. Pine Run Watershed.

Table C4.1. Physical Characteristics of Pine Run Watershed	
Physiographic Province	Piedmont
Area (square miles)	12
Predominant Land Use	Agriculture (37%) Forest land (37%) Developed land (26%)
Predominant Geology	Sandstone
Soils	
Dominant HSGs	C (47%) and B (31%)
K Factor	0.37
20-Year Average Rainfall (in)	40.4
20-Year Average Runoff (in)	4.5

C4.0.2 Surface Water Quality

A Total Maximum Daily Load or TMDL was developed for the Pine Run Watershed to address the impairments noted on Pennsylvania's 2002 Clean Water Act Section 303(d) Lists (see Table A1 in section A1.0). It was first determined that Pine Run and its unnamed tributary was not meeting its designated water quality uses for protection of aquatic life based on a 2001 aquatic biological survey. As a consequence of this survey, Pennsylvania listed Pine Run and its unnamed tributary on the 2002 Section 303(d) Lists of Impaired Waters.

The 2002 303 (d) List reported 7.1 miles of the Pine Run main stem and 1.3 miles of an unnamed tributary to be impaired by siltation and excessive algae growth. Stream segments of Pine Run Creek and its tributary 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 Pine Run is the result of years of 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 126% 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 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 conditions were observed during a reconnaissance survey of the Pine Run watershed. 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 Pine Run. Without effective storm water management practices and sediment traps, build-up of sediments will continue to occur in the stream.

C4.1 APPROACH TO TMDL DEVELOPMENT

The present TMDL addresses impairment by sediments in Pine Run stream segments as reported on the 2002 303(d) List. The excessive algae growth impairment caused by upstream impoundment 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 at new construction sites will reduce problems associated with algae growth as well. The TMDL was derived as follows:

C4.1.1 Excessive Algae Growth Resulting from Upstream Impoundment

A TMDL was not determined for excessive algae growth. It was assumed that addressing sediment loads (and its associated phosphorus load) through the use of urban BMPs will at the same time reduce excessive algae growth problems within the watershed.

C4.1.2 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 Pine Run stream segments. Sediments deposited in large quantities on the streambed were degrading the habitat of bottom-dwelling macroinvertebrates. The TMDL for the Pine Run watershed 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 126% between 1992 and 2000.

The objective of the TMDL process for Pine Run is to reduce the average loading rate of sediments in the impaired stream segment to levels equivalent to or slightly lower than the average loading rate ca. 1992. It is assumed that this load reduction will allow the biological community to return to the impaired stream segments. The TMDL endpoints established for this analysis are discussed in detail in the TMDL section. The listing for impairment caused by siltation is addressed through reduction of sediment loads.

C4.1.3 Watershed Assessment and Modeling

The AVGWLF model was run for the Pine Run watershed 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 the Pine Run watershed. Based on the use of 20 years of historical weather data, the mean annual loads for sediments, N and P for the 1992 and 2000 land use/cover conditions are shown in Tables C4.2 and C4.3, 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 C4.4 presents an explanation of the header information contained in Tables C4.2 and C4.3. Modeling output for Pine Run watershed for 1992 and 2000 land use conditions is presented in Appendix F.

C4.2 LOAD ALLOCATION PROCEDURE FOR SEDIMENT TMDL

The load allocation and reduction procedures were applied to the entire Pine Run watershed. For the sediment TMDL, 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 the Pine Run watershed.

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

$$TMDL = MOS + LA + WLA \tag{1}$$

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 “land development” 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.

Table C4.2. Loading Values for Pine Run Watershed, Year 1992 Land Use Conditions

Land Use Category	*Area (acres)*	*Sediment Load (lbs/year)*	*Unit Area Sediment Load (lbs/acre/yr)*
Hay/Pasture	657	25,320	38.54
Cropland	2,980	1,273,488	427.35
Coniferous Forest	86	110	1.27
Mixed Forest	612	1,722	2.81
Deciduous Forest	2,069	8,344	4.03
Unpaved Road	2	1,810	905.00
Transitional land	40	24,409	610.23
Low Intensity Dev	627	15,519	24.51
High Intensity Dev	212	6,452	30.43
Stream Bank		803,091	
Groundwater			
Point Source			
Septic Systems			
Total	7,286	2,160,265	296.49

Table C4.3. Loading Values for Pine Run Watershed, Year 2000 Land Use Conditions

Land Use Category	*Area (acres)*	*Sediment Load (lbs/year)*	*Unit Area Sediment Load (lbs/acre/yr)*
Hay/Pasture	610	23,969	39.29
Cropland	2,040	746,981	366.17
Coniferous Forest	86	110	1.28
Mixed Forest	611	1,722	2.82
Deciduous Forest	1,967	7,572	3.85
Unpaved Road	2	1,854	750.99
Transitional land	1,106	2,441,347	2207.02
Low Intensity Devel	643	16,291	25.38
High Intensity Devel	221	5,629	25.61
Stream Bank		844,150	
Groundwater			
Point Source			
Septic Systems			
Total	7,286	4,089,625	561.30

Table C4.4 Header Information for Tables C4.2 and C4.3.

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

C4.2.1 Sediment TMDL Total Load

As noted earlier, the TMDL total target load for the Pine Run watershed is based on the sediment load obtained using the 1992 land use conditions, and are equal to 2,160,265 lbs/year (see Table C4.2).

C4.2.2 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)   2,160,265 lbs/yr x 0.1 = 216,026 lbs/yr   (2)

C4.2.3 Waste Load Allocation

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)   2,160,265 lbs/yr – 216,026 lbs/yr = 1,944,239 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.

C4.2.4 Sediment Load Reduction Procedures

The allocation of sediment among contributing land use/cover sources in the Pine Run watershed was done by reducing each source equally on a percentage basis. Based on the target

WLA of 1,944,239 lbs/year described above, the computed load allocations are those shown in Table C4.5.

Table C4.5 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	657	25,320	23,969	11,395	52
Cropland	2,980	1,273,488	746,981	355,115	52
Coniferous Forest	86	110	110	53	52
Mixed Forest	612	1,722	1,722	819	52
Deciduous Forest	2,069	8,344	7,572	3,600	52
Unpaved Road	2	1,810	1,854	882	52
Transitional land	40	24,409	2,441,347	1,160,640	52
Low Intensity Devel	627	15,519	16,291	7,745	52
High Intensity Devel	212	6,452	5,629	2,677	52
Stream Bank Erosion		803,091	844,150	401,313	52
Groundwater					
Point Source					
Septic Systems					
Total	7,286	2,160,265	4,089,625	1,944,239	52

The total allowable sediment load in the Pine Run watershed when all sources of sediment are considered (as well as the 10% MOS) is 1,944,239 lbs per year. In order for all stream segments to attain their specific uses, the total sediment load should be reduced from 4,089,625 lbs per year by a factor of 52%.

C4.3 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 this TMDL using average annual conditions is protective of the waterbody.

C4.4 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.

C4.5 REASONABLE ASSURANCE OF IMPLEMENTATION

Sediment reductions in the TMDL are allocated to developed land uses 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 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 the Pine Run Creek watershed 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. 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 nutrient and sediment reductions outlined in this section.

C4.6 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 TMDLs. Notice of final TMDL approval will be posted on the Department website.