Executive Summary

Total Maximum Daily Load of Nutrients
for Lake Nockamixon, Bucks County, Pennsylvania

TMDL AT A GLANCE

303(d) Listed Waterbody:	Yes
Year Listed:	1996
Segment ID:	3110 (State water plan 2-D)
HUC:	02040105
Cause of Listing:	Nutrients and sediment
Source of Pollutants:	Agriculture, municipal point sources, on-site wastewater
Data Source:	Clean Lakes Project, Phases I and II
Designated Uses:	Trout stocked fishery, warm water fishes, potable water supply, industrial water supply, livestock water supply, wildlife water supply, irrigation, boating, fishing, water contact sports, and aesthetics
Size of Waterbody:	1,450 acres
Size of Watershed:	46,700 acres
Applicable Water Quality Standards:	General water quality criteria
Water Quality Target:	Chlorophyll-a (in-lake concentration of 10 ug/L)
Nutrient of Concern:	Total phosphorus
Technical Approach:	AVGWLF watershed model BATHTUB lake water quality model
TMDL:	862.92 lb/month total phosphorus
WLA:	531.98 lb/month total phosphorus
LA:	287.79 lb/month total phosphorus
MOS(5 percent):	43.15 lb/month total phosphorus

Lake Nockamixon is located approximately 8 miles east of Quakertown in Bucks County, Pennsylvania. The lake was originally created by the Pennsylvania Department of Environmental Protection (DEP) in 1973 and encompasses almost 1,450 acres. The surrounding watershed contains about 46,700 acres consisting mainly of forested areas and croplands. Pennsylvania listed Lake Nockamixon on the 1996 303(d) list of the Clean Water Act (CWA) as impaired by nutrients and sediment from agriculture, municipal point sources, and on-site wastewater sources based on the Clean Lakes Project Reports, Phases I and II. These reports documented elevated nutrient levels and algal blooms that impaired the designated uses of Lake Nockamixon. Lake Nockamixon was classified as hypereutrophic. Section 303(d) of the CWA and its implementing regulations require a total maximum daily load (TMDL) to be developed for those waterbodies identified as impaired by the state where technology-based and other controls did not provide for attainment of water quality standards.

The watershed and water quality analysis indicated that sediments is not currently impairing Lake Nockamixon. This finding is based on sediment loads as determined by the ArcView Generalized Watershed Loading Function (AVGWLF) and takes into account the loss of lake volume, and subsequent use impairment, typically associated with elevated sedimentation rates.

Existing data did not document in-lake use impairments or other in-lake problems due to sediment. Therefore, a TMDL for sediment is not justified or necessary at this time.

The goal of the TMDL for nutrients is to reduce phosphorus loadings to the lake so that chlorophyll-a levels in Lake Nockamixon stay at or below 10 ug/L as a seasonal average. This will result in Lake Nockamixon being classified as mesotrophic. The TMDL is accomplished by reducing nonpoint source total phosphorus contributions from cropland, hay/pasture land, and streambank areas. Point source contributions of phosphorus will be maintained at their permitted levels.

To estimate the amount of total phosphorus loading to Lake Nockamixon from both point and nonpoint sources, AVGWLF model is used. The output from AVGWLF is used by the in-lake water quality model BATHTUB to predict chlorophyll-a concentrations in Lake Nockamixon and develop various loading scenarios and management alternatives. Total phosphorus loadings as determined by the AVGWLF model are reduced until predicted chlorophyll-a levels in Lake Nockamixon are consistent with the water quality target of 10 ug/L. Total phosphorus reductions are targeted to source areas that have the ability to be controlled through various measures such as best management practices (BMPs).

The Pennsylvania DEP identified 16 point sources in the Lake Nockamixon watershed. The Quakertown Waste Water Treatment Plant was determined to be the largest point source contributor of total phosphorus to Lake Nockamixon. Thirteen of the identified point sources in the Lake Nockamixon watershed already have effluent limitations for total phosphorus of 0.5 mg/L. The remaining three point sources were required to reduce effluent limitations for total phosphorus from 1.0 mg/l to 0.5 mg/l. These three permits have been issued, however, the facilities have not yet been constructed and discharges have not occurred.

Approximately 63 percent of the Lake Nockamixon watershed is forested and 26 percent is cropland and hay/pasture land. The remaining acreage of the watershed is distributed among low and high development, wetlands, transitional lands, paved roads, and water. The TMDL of phosphorus requires reductions from hay/pasture lands, croplands, and streambank areas based on the source loading analysis that indicated these three sources as the largest nonpoint source contributors of total phosphorus. Background concentrations of total phosphorus are included by incorporating groundwater contributions and existing in-lake phosphorus concentrations as indicated by existing and readily available data.

FINAL REPORT

Total Maximum Daily Load of Nutrients for Lake Nockamixon in Bucks County, Pennsylvania

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Table of Contents

Executive Summary ES-1

1.0 Problem Understanding 1-1
1.1 Watershed Description 1-1
1.2 Socioeconomic Characteristics 1-7
1.3 303(d) Listed Waterbodies 1-9
1.3.1 Lake Eutrophication 1-10
1.3.2 Nutrient Cycling and Transport 1-11
1.3.3 Nutrient Limitation 1-11
1.3.4 Sedimentation 1-12
1.4 Water Quality Standards 1-13
1.5 Suspended Solids Impairment 1-14
1.6 Numeric Water Quality Target 1-14
1.7 Existing Chlorophyll-a Concentrations in Lake Nockamixon 1-14

2.0 Source Assessment 2-1
2.1 Data Inventory 2-1
2.1.1 Stream Flow Data and Lake Hydrology Data 2-2
2.1.2 Water Quality Data 2-4
2.1.2.1 Legacy STORET Data 2-4
2.1.2.2 EPA Clean Lakes Program Phase I and II 2-7
2.1.2.3 Pennsylvania DEP Data 2-9
2.1.2.4 Bucks County Conservation District (BCCD) Data 2-9
2.1.2.5 Miscellaneous Data 2-10
2.1.2.6 Modern STORET data 2-10
2.1.3 Additional Descriptive Datasets 2-10
2.2 Point Sources Data 2-11
2.2.1 Permitted Point Sources 2-11
2.2.2 Discharge Monitoring Report Data 2-14
2.3 Nonpoint Sources Data 2-14
2.3.1 Septic Systems 2-14
2.3.2 Groundwater Nutrient Concentration 2-14
2.4 Land Use Data 2-14
2.5 Meteorological Data 2-17

3.0 Technical Approach 3-1
3.1 Technical Approach 3-1
3.1.1 Water Quality Endpoints 3-1
3.1.2 Dominant Processes 3-1
3.1.3 Scale of Analysis 3-1
3.1.4 Technical Approach for Lake Nockamixon 3-2
3.2 Watershed Model – AVGWLF 3-2
3.2.1 GIS-Based Derivation of Input Data 3-5
3.2.2 Critical Condition and Seasonal Environmental Variation 3-7
3.2.3 Background Pollutant Contributions 3-8

3.2.4 Explanation of Important Model Parameters 3-9
3.2.5 Hydrology Calibration and Validation 3-9
3.2.6 NonPoint Source Loads Evaluation 3-10
3.2.7 Point Source loads Evaluation 3-11
3.2.8 Significant sources of Sediment and Phosphorous Loads 3-11
3.3 Lake Nockamixon Water Quality Model – BATHTUB 3-12
3.3.1 Model Setup 3-13
3.3.2 Critical Conditions and Seasonal Environmental Variation 3-15
3.3.3 Background Pollutant Contributions 3-15
3.3.4 Model Calibration and Verification 3-15

4.0 TMDL Development 4-1
4.1 Sediment Loading Analysis 4-1
4.2 Phosphorus Loading Analysis 4-5
4.3 TMDL Allocations of Phosphorus 4-8
4.4 Load Allocations of Phosphorus 4-8
4.5 Wasteload Allocations of Phosphorus 4-10
4.6 Margin of Safety 4-11
4.7 Reasonable Assurance 4-12

Figures . . . .
F1-1 Lake Nockamixon watershed 1-2
F1-2 Major tributaries 1-3
F2-1 USGS gage stations 2-3
F2-2 STORET stations 2-6
F2-3 Lake sampling stations 2-8
F2-4 Point sources 2-13
F2-5 Land uses 2-16
F2-6 Weather stations 2-18
F3-1 Subwatershed delineations 3-3
F3-2 Hydrology calibration 3-10
F3-3 BATHTUB segmentation of Lake Nockamixon 3-14
F3-4 BATHTUB Calibration plots 3-16
F3-5 BATHTUB verification plots 3-17
F4-1 Sediment depositional areas in Lake Nockamixon 4-4
F4-2 Predicted chlorophyll-a concentrations using design conditions 4-7

Pictures . . . .
P1-1 View of Lake Nockamixon from Dam 1-4
P1-2 View of Haycock Creek 1-5
P1-3 View of Tohickon Creek 1-6
Tables . . . .
T1-1 Socio-economic characteristics of Bucks County 1-7
T1-2 Number of paid employees by sector 1-8
T1-3 Pennsylvania 303(d) listed waterbodies 1-9
T1-4 Trophic State characteristics 1-11
T1-5 Total Nitrogen to Total Phosphorus ratios 1-12

T1-6 Water Quality Standards 1-13
T1-7 Existing chlorophyll-a concentrations in Lake Nockamixon 1-15
T2-1 Inventory of Data 2-1
T2-2 Summary of USGS data 2-2
T2-3 Lake Nockamixon characteristics 2-2
T2-4 STORET data 2-4
T2-5 NPDES point source dischargers 2-11
T2-6 Land uses 2-15
T2-7 Meteorological stations 2-17
T3-1 Statewide GIS datasets 3-5
T3-2 Descriptive statistics for precipitation and streamflow 3-7
T3-3 Significant nutrient loads in Lake Nockamixon 3-12
T3-4 BATHTUB segment characteristics 3-13
T4-1 Displaced lake volume from sedimentation and life span of Lake Nockamixon . 4-2
T4-2 TMDLs of phosphorus in Lake Nockamixon 4-8
T4-3 Load allocations of phosphorus in Lake Nockamixon 4-8
T4-4 Percent reductions necessary to meet load allocations 4-11
T4-5 Individual wasteload allocations of phosphorus in Lake Nockamixon 4-11

Literature Cited R-1

Appendices . . . .
Appendix A - List of Important Parameters for AVGWLF model execution A-1
Appendix B - Simulated Annual and Monthly Nonpoint Source Phosphorus Loads . . B-1
Appendix C - Monthly Point Source Phosphorus Loads in Tohickon Creek WatershedC-1
Appendix D - Monthly Point Source Phosphorus Loads in Threemile Run Watershed D-1
Appendix E - Simulated Annual Sediment Loads E-1
Appendix F - Baseline condition point source effluent limitations F-1
Appendix F - Comment and Response G-1

1.0 Problem Understanding

Section 303(d) of the Clean Water Act (CWA) requires states to list those waterbodies as impaired where technology-based and other controls could not provide for the attainment of water quality standards. Furthermore, the Environmental Protection Agency's (EPA's) *Water Quality Planning and Management Regulations* (40 CFR 130) require states to develop Total Maximum Daily Loads (TMDLs) for waters that are exceeding water quality standards. Pennsylvania listed Lake Nockamixon as impaired on the 1996 303(d) list of impaired waterbodies. In settlement of *the American Littoral Society, et al. v. EPA, No. 96-489 (E.D. Pa.)*, a consent decree was signed that set forth a 12-year schedule to establish TMDLs for approximately 575 listed waterbodies on Pennsylvania's 303(d) list. The consent decree also requires EPA to backstop development of these TMDLs.

Lake Nockamixon is listed as affected by suspended solids and nutrients from agriculture, municipal point sources, and on-site wastewater sources. Lake Nockamixon was initially listed on the 1996 303(d) list and given high priority for development. Therefore, a TMDL of nutrients is being developed for Lake Nockamixon. Watershed assessment and water quality analysis indicated that a TMDL for sediments is not justified or necessary at this time. The assessment of and analysis documenting this finding are explained in Section 4 of this report.

1.1 Watershed Description

The Lake Nockamixon[1] (Picture 1-1) watershed encompasses approximately 46,700 acres and is located in Bucks County, Pennsylvania, in the Schuylkill River basin (HUC 02040105) (Figure 1-1). Lake Nockamixon lies within the Nockamixon State Park,[2] which offers opportunities for horseback riding, swimming, fishing, boating, hiking, hunting, and picnicking. In fact, Nockamixon State Park is one of the largest and most popular parks in this region of Pennsylvania with more than 1 million visitors annually. The major tributaries (Figure 1-2) to the reservoir are Haycock Creek (Picture 1-2), Tohickon Creek (Picture 1-3), and Threemile Run. The Tohickon Creek is fed by numerous unnamed and named tributaries including Bog Run, Morgan Creek, Beaver Run, and Dry Run. Lake Nockamixon sits at an elevation of 395 feet and drains into Tohickon Creek, which is a direct drainage tributary of the Delaware River. The majority of the lake is underlain by red shales, with the northern portion of the lake underlain by igneous diabase.

[1] Lake Nockamixon, which encompasses 1,450 acres, was created by the Department of Environmental Protection in 1973.

[2] Nockamixon State Park encompasses approximately 5,253 acres in upper Bucks County, 5 miles east of Quakertown.

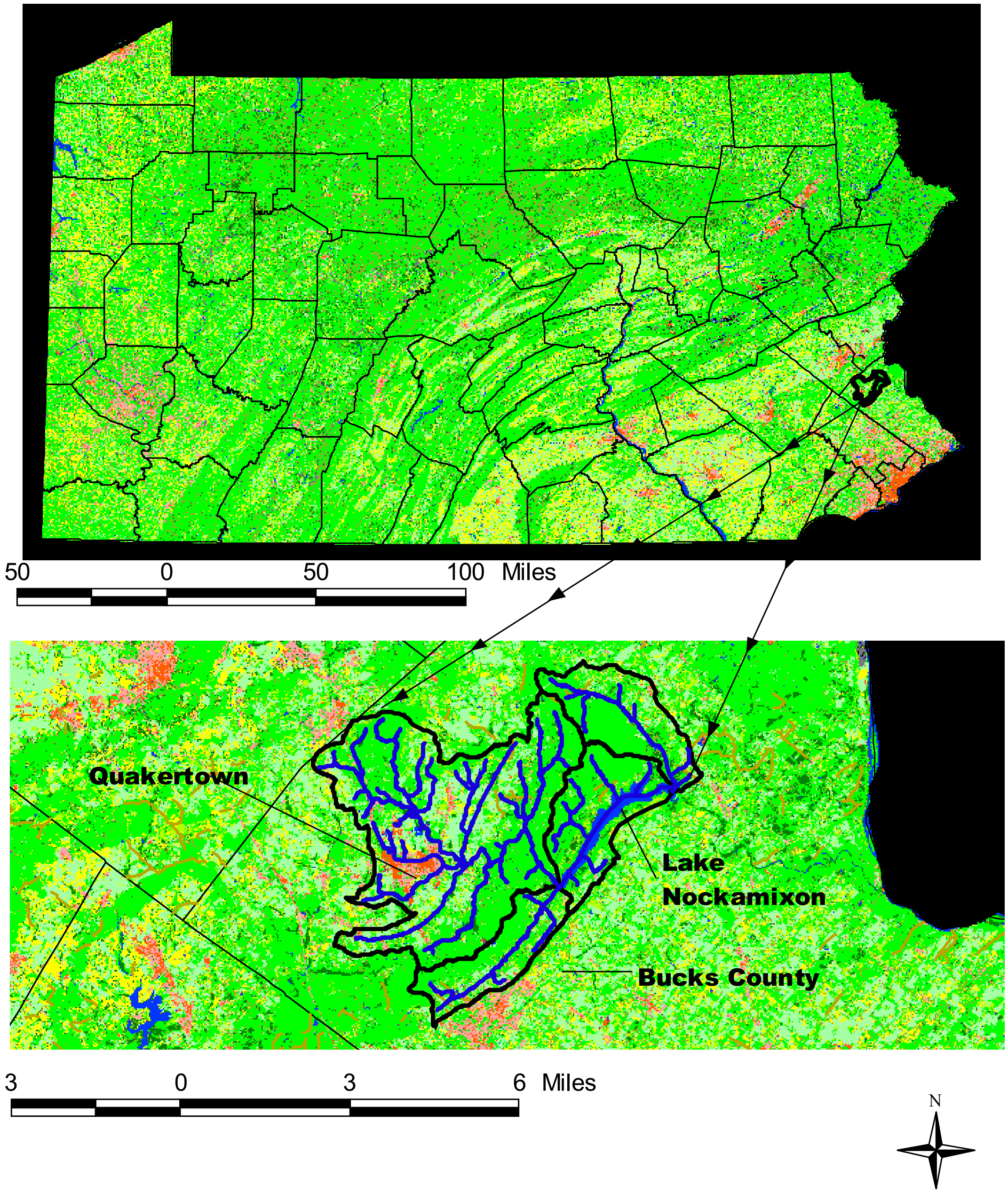

Figure 1-1. Location of Lake Nockamixon watershed

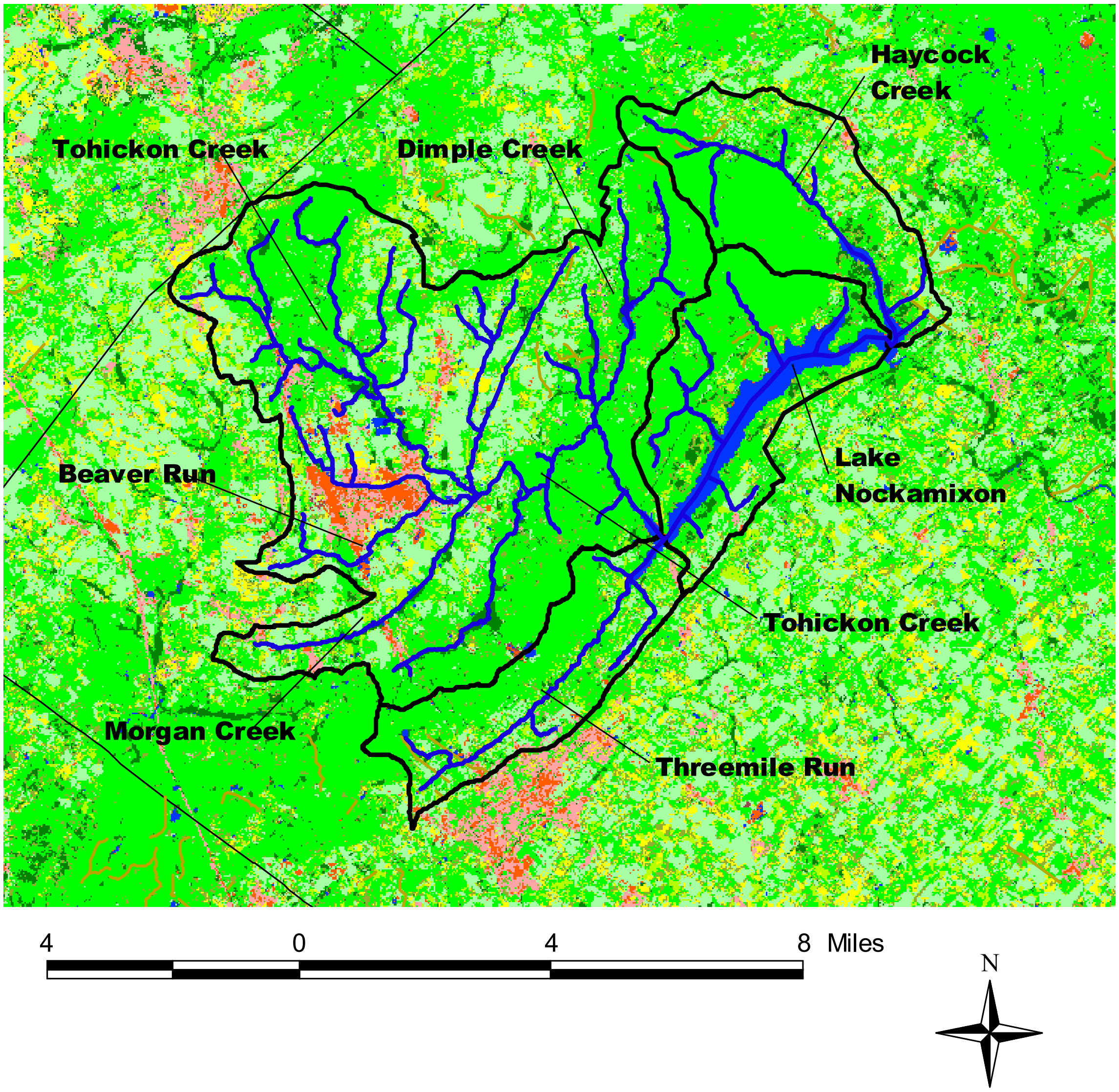

Figure 1-2. Major tributaries and waterbodies in the Lake Nockamixon watershed**.**

Picture 1-1. View of Lake Nockamixon from the dam.

Picture 1-2. View looking upstream at Haycock Creek from Church Lane.

Picture 1-3. View looking upstream at Tohickon Creek from Mountain View Drive**.**

1.2 Socioeconomic Characteristics

As of 2001, the U.S. Census Bureau estimates the population of Pennsylvania at 12,287,150. This represents an increase of only 6,096 since 2000, which is less than 0.05 percent. This is well below the national population increase for the same period of 1.2 percent The overall population change during the period 1990 to 2000 was 3.4 percent. Again, this is well below the national population increase from 1990 to 2000 of 13.1 percent. The median household income in Pennsylvania in 1997, based on model estimates, was $37,297, slightly above the national median household income of $37,005.

Bucks County experienced demographic changes that more closely mirrored national patterns. In Bucks County, population increased from 597,635 to 605,379 during the period 2000 to 2001, an increase of 1.3 percent. This is slightly above the national population growth rate of 1.2percent. During the period 1990-2000, Bucks County experienced population growth of 10.4percent, slightly below the national population growth rate of 13.1percent. The median household income, based on model estimates, in Bucks County was $54,664, almost $17,000 higher than the national median household income.

Bucks County encompasses almost 607 square miles and has about 985 people per square mile. This indicates how densely populated Bucks County is compared to the state of Pennsylvania, which has 274 people per square mile, or the entire country, which has almost 80 people per square mile. The top five economic sectors in the state, in terms of paid employees, from largest to smallest, are manufacturing, retail trade, health care and social assistance, accommodation and food service, and finance and insurance. In Bucks County, the top five economic sectors by paid employees from largest to smallest are manufacturing, retail trade, wholesale trade, administration and support (including waste management and remediation), and accommodation and food services. Table 1-1 summarizes the socioeconomic statistics for the state. Table 1-2 lists the number of paid employees in the economic sector.

Table 1-1. Summary of Socio-economic statistics

Category	Bucks County	Pennsylvania	USA
Pop. 2001 estimate	605,379	12,287,150	284,796,887
Pop. percent change April 1, 2000 to July 1, 2001	1.3	0.05	1.2
Pop. 2000	597,635	12,281,054	281,421,906
Pop. Percent change 1990 to 2000	10.4	3.4	13.1
Median household money income	$54,664	$37,267	$37,005
Land area 2000 (square miles)	607	44,817	3,537,441

Persons per sq. mile (2000)	984.6	274.0	79.6

Source: The U.S. Census Bureau website at http://www.census.gov/.

Table 1.2-Number of paid employees by economic sector

Economic Sector	Bucks County	Pennsylvania	USA
Manufacturing	41,592 **(1)**	826,521 **(1)**	16,888,016 **(1)**
Retail trade	36,195 **(2)**	650,144 **(2)**	13,991,103 **(2)**
Health care and social assistance	-	453,579 **(3)**	7,329,811 **(5)**
Accommodation and food services	15,741 **(5)**	365,158 **(4)**	9,451,226 **(3)**
Finance and insurance	-	287,143 **(5)**	-
Administrative and support (including waste management and remediation)	15,779 **(4)**	-	7,347,366 **(4)**
Professional, scientific, and technical services	-	-	-
Wholesale trade	16,257 (3)	-	-

Source: The U.S. Census Bureau website at http://www.census.gov/epcd/www/econ97.html.

1.3 303(d) Listed Waterbodies

As stated earlier, the Pennsylvania 1996 303(d) list contained approximately 575 impaired waterbodies (Table 1-3). Lake Nockamixon, in State Water Plan 02-D, was listed based on data from the EPA Clean Lakes Project, which funded a Phase I Diagnostic Feasibility Study in 1982 to evaluate the environmental condition of Lake Nockamixon as well as the Phase II Implementation Project from 1988 to 1991. Using these studies and Trophic Status Index (TSI) studies performed by the Pennsylvania DEP Southeast Regional Office (SERO), Pennsylvania listed 1,450 acres of Lake Nockamixon as impaired by suspended solids and nutrients from agriculture, on-site wastewater discharges, and municipal point sources in 1996 (See Figure 1-2). Lake Nockamixon is also listed on the 2002 Pennsylvania 303(d) list as medium priority for TMDL development.

Table 1-3. 303(d) Selected Listed waterbodies in State Water Plan 02-D

Waterbody Name	Segment ID	Listing Date	Miles or Acres Affected	Aquatic Life	Pollutant	Source	TMDL Priority
Lake Nockamixon	3110	1998	1,450 acres	x	nutrients and suspended solids	agriculture	medium
				x	nutrients and suspended solids	municipal point source	medium
				x	nutrients and suspended solids	on-site wastewater discharge	medium
Morgan Creek	20010727-1430-ACW	2002	2.5 miles	x	nutrients	small residential runoff	medium
				x	siltation	road runoff	medium
Threemile Run	20010706-1400-ACW	2002	4.2 miles	x	nutrients	removal of vegetation	medium
				x	flow alterations	road runoff	low
Tohickon Creek	20010619-1600-ACW	2002	5.3 miles	x	siltation	removal of vegetation	medium
				x	nutrients	agriculture	medium
	20010713-1400-ACW	2002	9 miles	x	nutrients	agriculture	medium
				x	siltation	removal of vegetation	medium

Note: Lake Nockamixon segment ID on the 2002 Pennsylvania 303(d) list is 950501-0010-LAK.

There are seven other named aquatic life use streams listed as impaired on the 2002 303(d) list in State Water Plan 02-D including Morgan Creek, Threemile Run, and Tohickon Creek, which are part of the Lake Nockamixon watershed. Morgan Creek, segment ID 20010727-1400-ACW, is listed as impaired by nutrients and siltation from small residential runoff and road runoff, respectively. Threemile Creek, segment ID 20010706-1400-ACW, is listed as impaired by nutrients and flow alterations from removal of vegetation and road runoff, respectively. These two creeks and their respective cause/source impairment combinations are given medium and low priority and are being listed on the 2002 303(d) list. Tohickon Creek has two segments listed on the 2002 303(d) list that were not originally listed on the 1996 303(d) list. Segment 20010619-1600-ACW is impaired by siltation and nutrients from the removal of vegetation and agriculture. Segment 20010713-1400-ACW is listed as impaired by nutrients and siltation from agriculture and the removal of vegetation. All cause/source impairment combinations in Tohickon Creek are given medium priority.

It is important to note that the focus of this effort is to address the impairments in Lake Nockamixon as listed on the 1996 303(d) list and to develop a TMDL to address those impairments. The 2002 Pennsylvania 303(d) list has been submitted to EPA Region 3 for review and approval; however, the 2002 303(d) list is not applicable until EPA approves it.

Previous studies have investigated the impairments as a result of excessive nutrients and sedimentation. The Phase I study documented that Lake Nockamixon is hyper-eutrophic suffering from high nutrient concentrations, frequent algal blooms, low transparency levels, and anoxic conditions in the hypolimnion during summer. Elevated sedimentation rates have reduced the storage capacity of the lake and caused deterioration of fisheries and recreational uses. Lake water quality improved as a result of reduced effluent limitations for the Quakertown wastewater treatment plant, which discharges into Tohickon Creek, and agricultural best management practices implemented as a result of the Phase II implementation project. Education regarding land use has also helped improve water quality. However, all these factors together were not enough to ensure that the lake could attain and maintain water quality standards.

1.3.1 Lake Eutrophication

Lake eutrophication is both a natural and a 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.[3] 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 that 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 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 that 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.[4] Table 1-4 illustrates the typical water quality variables of these three trophic designations.

[3] *Modeling Phosphorus Loading and Lake Response under Uncertainty: A manual and compilation of Export Coefficients*, 1980, EPA 440/5-80-011.

[4] *Technical Guidance Manual for Performing Water Load Allocations, Book IV, Lakes and Impoundments, Chapter 2, Nutrient/Eutrophication Impacts*, 1984, EPA 440/14-84-019.

Table 1-4. Trophic-state classifications and typical lake conditions

Variable	Trophic-state Classifications		
	Oligotrophic	Mesotrophic	Eutrophic
Total Phosphorus (ug/l P L^{-1})	<10	10-20	>20
Chlorophyll-a (ug/l Chl-a L^{-1})	<4	4-10	>10
Secchi-disk depth (m)	>4	2-4	<2
Hypolimnion oxygen (% saturation)	>80	10-80	<10

Source: *Principles of Surface Water Quality Modeling and Control*,, Thomann, R.V., and Mueller, J.A., 1987

1.3.2 Nutrient Transport and Cycling

Nutrient transport is governed by several chemical, physical, and biological processes known as the nutrient cycle. The nitrogen cycle consists of four processes (nitrogen fixation, ammonification, nitrification, and denitrification) that convert nitrogen gas into usable nitrogen forms and back into nitrogen gas. Nitrogen fixation converts gaseous nitrogen into ammonia, whereas ammonification involves the breakdown of wastes and nonliving organic tissue into ammonia. The nitrification process oxidizes ammonia, which results in nitrate and nitrite. Finally, nitrates are converted back into gaseous nitrogen through the denitrification process. Ammonia ions, nitrites, and nitrates are most important for water quality assessments because of their impact on water quality. Organic nitrogen and particulate nitrogen are not as important for water quality assessments because they must be converted into usable forms.

Phosphorus transport is similarly governed by the phosphorus cycle. Since phosphorus does not exist as a gas like nitrogen, the primary source of phosphorus into the environment occurs due to the weathering of rocks. Once in the environment, phosphorus exists in either organic particulate or soluble inorganic form. In general, the soluble inorganic form is considered most important, however, in lakes, where residence time is longer than in streams. Ttotal phosphorus (organic and inorganic) is considered an adequate estimation of bioavailable phosphorus.

1.3.3 Nutrient Limitation

Nutrient limitation refers to a deficit of one particular nutrient (either nitrogen or phosphorus) required by microorganisms to metabolize substrate. When nutrient limitation occurs, the limited-nutrient typically controls algal growth in the waterbody. Algae growth becomes very sensitive to changes in the concentration of the limiting nutrient. Because phosphorus is normally scarce in the aquatic environment, it is often the major nutrient in shortest supply and is frequently a prime determinant of the total biomass.[5] Phosphorus is also the nutrient that is the most effectively controlled using existing engineering technology and land use management.[6]

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[5] *Modeling Phosphorus Loading and Lake Response under Uncertainty: A Manual and Compilation of Export Coefficients*, 1980, EPA 440/5-80-011.

[6] EPA 440/5-80-011. 1980.

Confirmation that phosphorus is the limiting nutrient in Lake Nockamixon can be determined by comparing the total nitrogen concentration to the total phosphorus concentration. According to Chapra (1997), nitrogen to phosphorus ratios higher than 7.2:1 indicate that phosphorus is the limiting nutrient. Table 1-5 below demonstrate the total nitrogen:total phosphorus ratios measured during sampling events in Lake Nockamixon. Thus, the TMDL is being developed for phosphorus.

Table 1-5. Total Nitrogen to Total Phosphorus Ratios in Lake Nockamixon.

Sampling Event	Sampling Period	Average TN:TP ratio
EPA Clean Lakes Project Phase II (FX Browne)	1988 through 1991	28.37
Pennsylvania DEP TSI Study	1995	13.88
	1999	7.91
	2000	20
	2001	40
Bucks County Conservation District (FX Browne)	1998	19.64
	1999	26.64
	2000	25.97

Schindler (1977) maintains that all freshwater lakes will eventually be phosphorus limited because other nutrients have an atmospheric pathway in their biogeochemical cycles and are thus more subject to internal regulation, whereas phosphorus cycling is strictly geologic and thus more sensitive to external factors[7].

1.3.4. Sedimentation

Excessive sedimentation can cause numerous problems depending on the waterbody's designated use. For waterbodies designated as aquatic life, sedimentation can choke spawning gravels, impair fish food sources, fill in rearing pools, and reduce habitat complexity or cause direct harm such as clogging gills. This also interferes with fishing uses. In drinking water supplies, excessive sediment can cause taste and odor problems, block water supply intakes, foul treatment systems, and fill reservoirs. Excessive sedimentation may also inhibit swimming and boating and may have aesthetic impacts from reduced water clarity (US EPA, 1999(b)). Sediment transport occurs as a result of overland erosional processes, such as sheetwash, gully and rill erosion, or human excavation, or in-stream processes, such as channel and bank erosion.

[7] Schindler, D.W. 1977. Evolution of Phosphorus Limitation in Lakes. Science 195:260-262.

1.4 Water Quality Standards

Water quality standards consist of three components: designated and existing uses, narrative and/or numerical water quality criteria necessary to support those uses, and an antidegradation statement. Furthermore, water quality standards have the dual purposes of establishing the water quality goals for a specific waterbody and serving 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 CWA (USEPA, 1991).

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. In addition, Lake Nockamixon is a designated trout stocked fishery as indicated by Chapter 93, Section 9e.

Pennsylvania does not have specific numeric water quality criteria for suspended solids or nutrients to support these uses. However, Pennsylvania does have general water quality criteria in Section 93.6 that state: *"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 apply only to public water supplies. Table 1-6 summarizes these criteria.

Table 1-6. Applicable Pennsylvania Water Quality Criteria

Parameter	WWF and other uses	TSF	HQ-CWF	CWF, HQ-WWF, HQ-TSF
Nutrients	n/a, general water quality criteria	n/a, general water quality criteria	n/a, general water quality criteria	n/a, general water quality criteria
Suspended Solids	n/a, general water quality criteria	n/a, general water quality criteria	n/a, general water quality criteria	n/a, general water quality criteria

WWF - Warm Water Fishery
TSF - Trout Stock Fishery
HQ-CWF - High Quality Cold Water Fishery
CWF - Cold Water Fishery
HQ-WWF - High Quality Warm Water Fishery
HQ-TSF - High Quality Trout Stocked Fishery

1.5 Suspended Solids Impairment

Lake Nockamixon was listed as impaired by suspended solids on the 303(d) list based on the EPA Clean Lakes Program Phase I and II studies as well as the Pennsylvania DEP TSI studies. Suspended solids in natural waters have two primary origins: the drainage basin and the photosynthetic process (Chapra, 1997). In addition to potentially causing reduced clarity, suspended solids impair designated uses through excessive accumulation of sediment and subsequent loss of reservoir volume. Excessive accumulation impairs recreational uses by reducing access and degrading the aesthetic character of the lake. In Lake Nockamixon, sediment accumulation from suspended solids is the primary concern. Excessive sediment accumulation impairs designated uses by causing the accelerated loss of reservoir volume. Neither the Clean Lakes reports nor the TSI studies document in-lake use impairments or other in-lake problems due to elevated suspended solids loading. However, sediment loading analysis is conducted as part of the technical approach to investigate the suspended solids impairment. The results of this analysis are reported in Section 4 and indicate that Lake Nockamixon is not currently impaired by suspended solids. This obviates the need to develop sediment TMDLs for Lake Nockamixon.

1.6 Numeric Water Quality Target

To develop the 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. In terms of nutrients, the overall goal of the TMDL is to improve the trophic status of Lake Nockamixon from hyper-eutrophic to mesotrophic. According to the trophic state index described in Table 1-4, four parameters are used to relate water quality with trophic state; however, chlorophyll-a will be used as the numeric water quality target. Chlorophyll-a is easy to measure, a valuable surrogate for algal biomass, and desirable as a water quality target because alga are either the direct (nuisance algal blooms) or indirect (high/low dissolved oxygen, 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 Nockamixon from hyper-eutrophic to mesotrophic, the water quality target to address nutrient impairments is 10 ug/L chlorophyll-a as a seasonal average. This represents the upper limit of the mesotrophic state.

1.7 Existing Chlorophyll-a Concentrations in Lake Nockamixon

In order to confirm the eutrophic condition of Lake Nockamixon, existing and readily available data was analyzed to determine existing chlorophyll-a concentrations. Table 1-7 lists chlorophyll-a concentrations discovered in Lake Nockamixon according to sampling date.

Table 1-7. Chlorophyll-a concentrations in Lake Nockamixon

Date	Source	Chlorophyll-a concentration (ug/l)
5/3/1995	Pennsylvania DEP	19.75
7/16/1995	Pennsylvania DEP	5.05
9/6/1995	Pennsylvania DEP	5.15
7/31/1996 & 8/28/1996	Bucks County Conservation District	11.03
7/14/1997	Bucks County Conservation District	8.5
8/14/1997	Bucks County Conservation District	8.9
7/21/1998	Bucks County Conservation District	10.7
8/19/1998	Bucks County Conservation District	11.2
7/12/1999	Bucks County Conservation District	9.5
8/12/1999	Pennsylvania DEP	5.3
8/17/1999	Bucks County Conservation District	4.2
7/18/2000	Bucks County Conservation District	12.9
8/21/2000	Bucks County Conservation District	12.3
9/12/2000	Pennsylvania DEP	12.5
8/14/2001	Pennsylvania DEP	19.6
9/9/2002	Pennsylvania DEP	0.0

While the data show an increased level of variability, the majority of the samples indicate that Lake Nockamixon is eutrophic based on chlorophyll-a concentrations. In addition, chlorophyll-a concentrations appear to have been increasing over the last 3 years. These data document water quality standards impairment and the eutrophic status of Lake Nockamixon indicating the need to develop TMDLs for nutrients.

2.0 Source Assessment

The source assessment provides greater detail on the type, magnitude, timing, and location of nutrient loading to the impaired waterbody. It helps to determine the nutrient inputs that will support the TMDL analysis and development.

2.1 Data Inventory

Extensive data and a wide range information have been reviewed for the Lake Nockamixon watershed. The categories of data examined include physiographic data describing physical conditions of the watershed, environmental monitoring data identifying potential pollutant sources and contributions to the lake and its tributaries, hydrologic flow data, and water quality monitoring data. Table 2-1 summarizes the various data types and data sources reviewed and collected. Please note that no new data were collected to complete the TMDL analysis and development.

Table 2-1. Inventory of Data for the Lake Nockamixon Watershed

Data Category	Description	Data Source(s)
Watershed Physiographic Data	Land Use (National Land Cover Data)	USGS, AVGWLF, US EPA BASINS
	Stream Reach Coverage	USGS, AVGWLF, US EPA BASINS
	Weather Information	National Climatic Data Center, National Weather Service
Hydrologic data	Stream Flow Data	USGS
Environmental Monitoring Data	303(d) Listed Water	Pennsylvania DEP, US EPA
	Clean Lakes Project	Pennsylvania DEP, Bucks County Conservation District
	TSI Study	Pennsylvania DEP SERO
	Ambient Water Quality Mini-Network Sampling Data	Pennsylvania DEP SERO
	NPDES Data	PCS, Pennsylvania DEP
	Groundwater Monitoring Data	Pennsylvania DEP
	Water Quality Monitoring Data	EPA STORET, Pennsylvania DEP SERO, Bucks County Conservation District

USGS - United States Geological Survey.
AVGWLF - ArcView Generalized Watershed Loading Function.
BASINS - Better Assessment Science.
Pennsylvania DEP SERO - Pennsylvania Department of Environmental Protection, Southeast Regional Office.
US EPA - United States Environmental Protection Agency.
EPA STORET - STOrage and RETreival System.

2.1.1 Stream Flow and Lake Hydrology Data

There are no active U.S. Geological Survey (USGS) gages in the Lake Nockamixon watershed. Nor is there any information available regarding historical stream flow data. The USGS National Water Information System (NWIS) website was queried multiple times to determine what USGS gages existed. One station, USGS gage 01459500, was found and is located approximately 3.5 miles downstream from the outlet site of Lake Nockamixon into the Tohickon creek near Pipersville, Pennsylvania. Data from this site begin in July 1935 and continue through the present. A second USGS gage (01472620) located close to the watershed was found, however, this gage is located on the East Branch Perkiomen. Table 2-2 shows the stream flow summary for the USGS station located downstream from Lake Nockamixon.

Table 2-2. Summary of USGS Data (as of September 11, 2002, based on 66 years of data)

USGS gage	Station name	Period of record	Minimum	Mean	Maximum
01459500	Tohickon Creek	July 1935 to present	0.6 ft^3/sec	18 ft^3/sec	345 ft^3/sec

Table 2-3 summarizes the characteristics of Lake Nockamixon. These lake characteristics were identified by FX Browne during development of the Phase I study. Figure 2-1 shows the location of identified USGS gage stations near the Lake Nockamixon watershed.

Table 2-3. Lake Nockamixon characteristics

Altitude of normal pool level	395 feet
Surface area	1,450 acres
Volume of normal pool level	13,000,000,000 gallons or 39,900 acre-feet
Mean depth	27.6 feet
Mean hydraulic residence time	0.54 years
Mean annual discharge	107 cubic feet per second

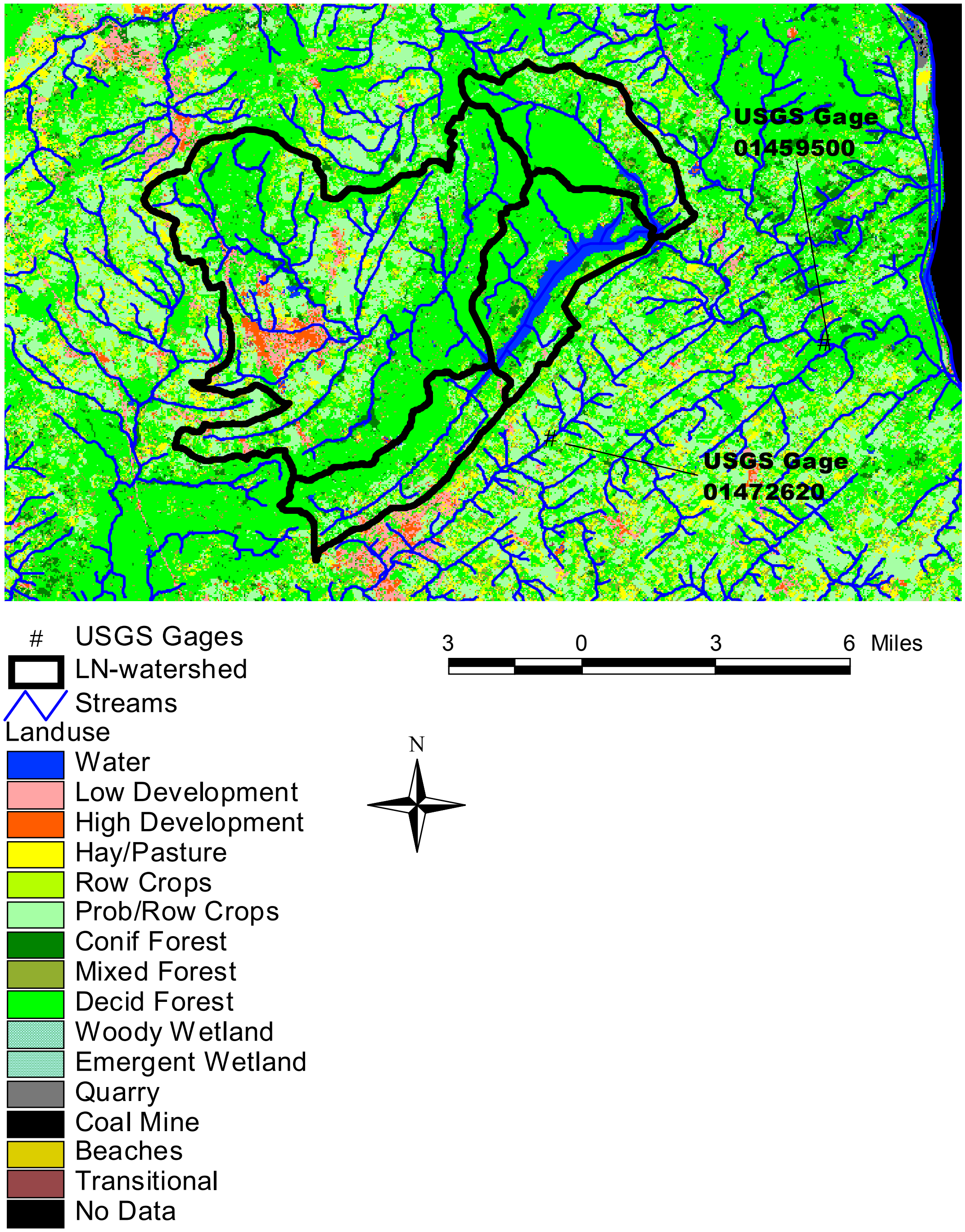


Figure 2-1. Location of USGS gaging stations in Lake Nockamixon watershed.

2.1.2 Water Quality Data

Pennsylvania's decision to list Lake Nockamixon on the 1996 303(d) list of impaired waterbodies was based in part on data from the Clean Lakes Project Phase I study performed in 1982. In addition, the Phase II Implementation Study from 1988 was used to confirm that Lake Nockamixon was still not meeting water quality standards. Data collected by the Pennsylvania DEP SERO during TSI evaluations in 1986, 1988, and 1995 were also used for listing purposes. A review of in-stream water quality data from EPA's STORET database has revealed limited data for the watershed.

2.1.2.1 Legacy STORET Data

The STORET system contained 3,045 data records from six stations located in Lake Nockamixon watershed(Figure 2-2). These data were collected by USGS. and the Pennsylvania DEP. Table 2-4 lists information about the data collected from STORET as well as the stations and period of record.

Table 2-4. STORET Data in the Lake Nockamixon Watershed

Agency	Station	Physical Location	Period of Record	Data characterization
USGS (112 WRD)	1459100	Beaver Run tributary at Quakertown, PA	4/19/1966 to 10/2/1968	Flow, nitrate-nitrogen, temperature
	1459150	Tohickon Creek near Quakertown, PA	4/23/1975 and 9/16/1975	Flow, temperature, dissolved oxygen, biochemical oxygen demand, nutrients
	1459182	Tohickon Creek near Quakertown, PA	9/22/1926 to 8/17/1976	Flow, temperature, dissolved oxygen, biochemical oxygen demand, nutrients
	402809075111200	Lake Nockamixon	7/30/1974 and 10/16/1992	Flow, temperature, dissolved oxygen, biochemical oxygen demand, nutrients
Pennsylvania DEP (21PA)	WQF03110-011.2	Lake Nockamixon (Tohickon Creek) Haycock Creek Cove	5/2/1990 and 7/1/1993	Fish tissue
	WQN0171	Tohickon Creek upstream from covered bridge on Bridge Road	1/19/1973 to 11/16/1987	Temperature, dissolved oxygen, nutrients

The majority of the STORET data in the watershed are almost 30 years old. Station WQF03110-011.2 consists of only fish tissue data, which will not be useful for this assessment. The data collected by USGS at stations 01479150 and 402809075111200 consists of flow, temperature, dissolved oxygen, biochemical oxygen demand, and nutrient data. However, the period of record is very limited, as the data were collected on only 2 days at each location. Data from station 1459100 contains only flow, temperature, and nitrate-nitrogen over 6 separate days from 1966 to 1968. Station 1459182 contains a variety of data including temperature, dissolved oxygen, nutrients, biochemical oxygen demand, and flow. However, the data are spread over a long period of record and data for parameters of concern are sporadic at best. No profile data is available at any of the USGS gages. Similar to USGS gage station 1459100, the Pennsylvania DEP station WQN0171 contains relevant data on temperature, dissolved oxygen, nutrients, and biochemical oxygen demand. There are no flow data from station WQN0171. Similar to USGS data, no profile data were available from station WQN0171. Very few, if any, chlorophyll-a or pheophytin samples were taken at any STORET stations in the Lake Nockamixon watershed.

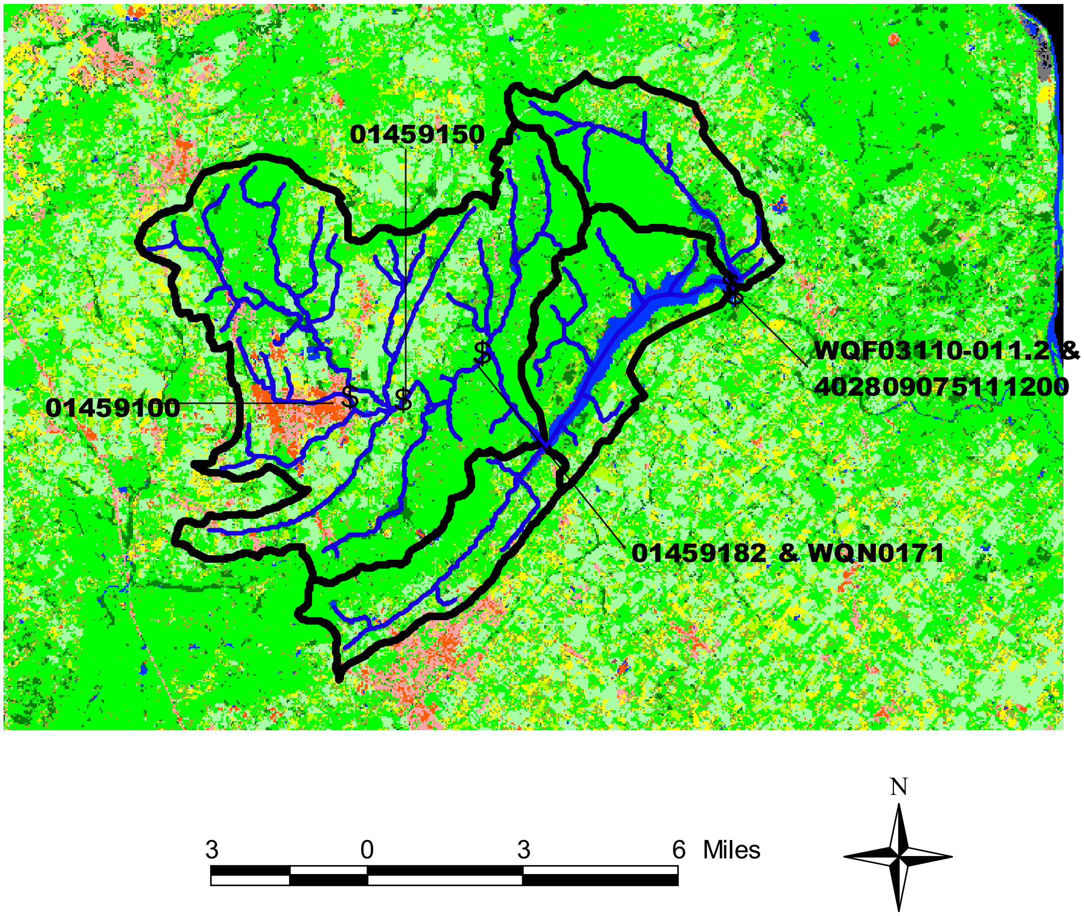


Figure 2-2. Location of STORET stations in the Lake Nockamixon watershed.

2.1.2.2 EPA Clean Lakes Program Phase I and II data

In addition to data from the STORET sampling stations, water quality data are available from three locations in Lake Nockamixon and from one location on each of the three major tributaries to Lake Nockamixon; those data were gathered by FX Browne as part of the Phase I Clean Lakes Study. Lake water samples were gathered from mid-April until mid-October 1982 and were analyzed for total phosphorus, dissolved reactive phosphorus, total suspended solids, the nitrogen series, chlorphyll-a, pheophytin a, fecal coliform bacteria, and secchi disk depth, as well as temperature and dissolved oxygen profiles. Station 1 was located near the upper end of the lake, station 2 was located mid-lake, while station 3 was located near the dam (Figure 2-3). Dry weather stream water quality samples on Tohickon Creek, Haycock Creek, and Threemile Run were collected monthly from April 1982 through March 1983. The stations for each of the three tributaries were located just upstream from the confluence with the reservoir. Wet weather water quality samples were collected during nine different storm events from November 1982 through March 1983 and were analyzed for total phosphorus, nitrogen, and suspended solids. The wet weather stations are located in the same location as the dry weather samples.

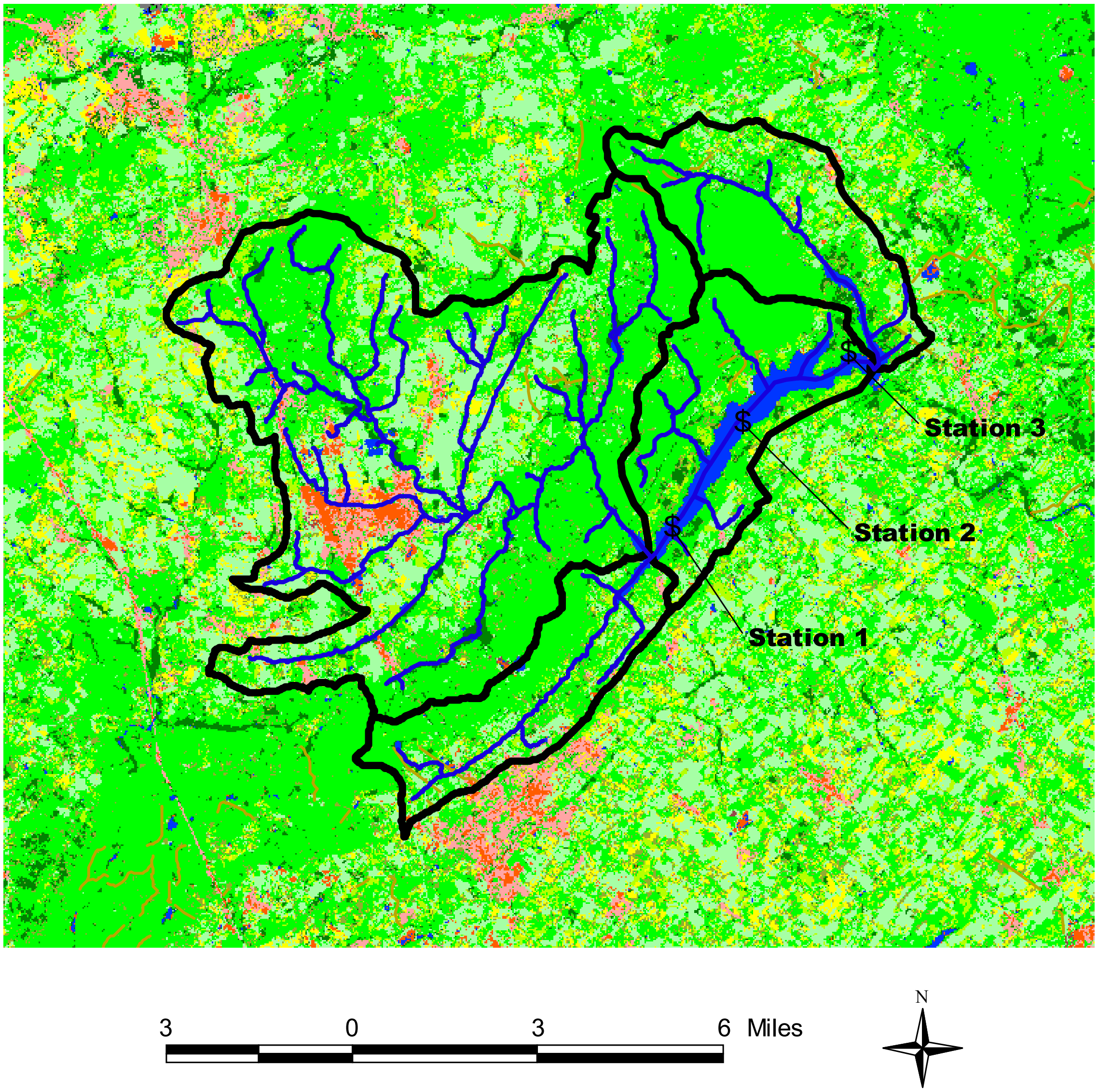


Figure 2-3. Location of lake sampling stations.

FX Browne also completed a Phase II Clean Lakes Study in September 1993. During this study, lake water quality samples were collected from three stations in the lake from 1988 through 1991 and analyzed for total phosphorus, orthophosphorus, ammonia nitrogen, nitrate-nitrite nitrogen, total Kjeldahl nitrogen, pH, alkalinity, total suspended solids, chlorophyll-a, and phytoplankton. Station 1 was located near the confluence with Tohickon Creek and station 2 was located mid-reservoir. Both of these stations were monitored monthly from May through August. Station 3 was located in the lake near the dam and was monitored monthly from January through April, biweekly from May through August, and monthly from September through December. Samples at each station were collected at surface, middle, and bottom depths. In addition, temperature and dissolved oxygen profiles were developed. The sampling locations from the Phase II study correspond to the sampling locations from the Phase I study.

2.1.2.3 Pennsylvania DEP data

The Pennsylvania DEP SERO also collected data on Lake Nockamixon. SERO collected surface and bottom samples at the mid-lake and near dam locations (stations 2 and 3 from the Phase I study) on Lake Nockamixon at least three times annually between May, and November in 1986, 1988 and 1995 for the TSI studies. Samples were analyzed for phosphorus, nitrogen, and Secchi disk depth, as well as profile measurements for pH, dissolved oxygen, temperature. Specific conductivity profiles were conducted at each station, along with samples for chlorophyll-a and pheophytin-a analysis in surface waters. Two vertical plankton tows were collected at each station.

As part of the Water Quality Network Program, SERO collected annual water quality samples, secchi disk depth, profile measurements, and two vertical plankton tows during 1999, 2000, and 2001 at the near dam station (station 3 from the Phase I study). The most recent sampling consists of a temperature/dissolved oxygen/pH/conductivity profile at 1-meter intervals at the deepest part of the lake during stratification, a vertical plankton tow, Secchi disk reading, chlorophyll-a analysis, and nutrient and metals sampling 1 meter from the surface and 1 meter from the bottom of the lake.

All Pennsylvania DEP TSI study data were collected in accordance with the Quality Assurance Work Plan: Evaluation of Phosphorus Discharges to Lakes, Ponds, and Impoundments effective June 10, 1997. These policies were set forth to establish and standardize the Pennsylvania DEP’s procedures for determining the need for phosphorus controls for lakes, ponds, and impoundments.

2.1.2.4 Bucks County Conservation District (BCCD) Data

Data from the Bucks County Conservation District, collected by FX Browne, are also available from 1996 through 2000. The data are collected at station 3 which was used in previous Lake Nockamixon studies performed by FX Browne. The data consist of monthly samples from July through August at surface and bottom water layers. Analyzed parameters include pH, alkalinity, total phosphorus, dissolved reactive phosphorus, ammonia nitrogen, nitrate-nitrite nitrogen, total

Kjeldahl nitrogen, total suspended solids, and fecal coliform. Dissolved oxygen and temperature profiles at 1-meter resolution were also collected. Composited water samples were measured for chlorophyll-a, phytoplankton, and zooplankton.

Information regarding quality assurance/quality control established by BCCD or its contractor was not available.

2.1.2.5 Miscellaneous Data

Data obtained from the Pennsylvania DEP Central Office were also compiled. This 2-day sampling event, performed by USGS on July 21, 1998 and August 19, 1998 near Lake Nockamixon dam, collected dissolved oxygen (DO) and temperature profile data as well as pH, ammonia nitrogen, nitrate-nitrite nitrogen, kjeldahl nitrogen, total phosphorus, and dissolved phosphorus. These data were obtained directly from the Central Office Lakes Program Office in electronic format. FX Browne used these data in its 1998 Lake Nockamixon water quality report to BCCD.

2.1.2.6 Modern STORET Data

The modern STORET database was queried for additional water quality samples in the Lake Nockamixon watershed. Unfortunately, no water quality data were available from the modern STORET database that would be of use for the development of TMDLs in the Lake Nockamixon watershed.

2.1.3 Additional Descriptive Datasets

The following datasets have also been acquired in preparation for TMDL analysis and development:

- Soils Data: State Soil and Geographic Database (STATSGO).
- Elevation Data: A 30-meter Digital Elevation Model (DEM) spatial coverage of the Lake Nockamixon basin is available and can be used with BASINS GIS software to perform watershed assessment and subwatershed delineation for modeling. The coverage provides land surface elevation in meters and feet.
- Stream Network Coverages: Reach File, Version 3 and the Pennsylvania DEP stream network, as well as spatial coverages of all 303(d) listed stream segments.
- Groundwater Concentrations: A statewide spatial coverage provides both nitrogen and phosphorus concentrations in groundwater based on recent studies by the Pennsylvania DEP and USGS to quantify the subsurface nutrient load delivered to the stream.
- Septic Systems: Information on the number of people served by septic systems based on 1990 Census tract data is used to calculate the nutrient load from septic systems.

2.2 Point Sources

Point sources, according to 40 CFR Section 122.3, are defined as any discernible, confined, and discrete conveyance, including but not limited to, any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, landfill leachate collection system, vessel or other floating craft from which pollutants are or may be discharged. The National Pollutant Discharge Elimination System (NPDES) Program, under CWA sections 318, 402, and 405, requires permits for the discharge of pollutants from point sources.

2.2.1 Permitted Point Sources

Permitted point sources include discharges such as municipal sewer systems, storm water systems, and water treatment plants. Table 2-5 lists permitted point sources identified by the Pennsylvania DEP in the Lake Nockamixon watershed. Figure 2-4 below shows the location of the 16 point sources identified by the Pennsylvania DEP, which also gathered this information. All point sources in the Lake Nockamixon watershed have effluent limitations for total phosphorus of 0.5mg/l except permits PA0058017, PA0058203, and PA0058548. These 3 permits have existing effluent limitations of 1.0 mg/l for total phosphorus. Five permits, PA0058017, PA0058203, PA0054364, PA0051993, and PA0058548, have been issued for treatment plants that have not yet been built.

Table 2-5. Permitted Facilities Discharging in the Lake Nockamixon watershed

Permit ID	Facility Name	Receiving Stream/Code	SIC-Type	Permit Type	Responsible Party
PA0020290	Borough of Quakertown	Tohickon Creek / 03110	4952-Sewerage systems	Standard-Major	David L. Woglom
PA0031178	Melody Lakes MHP	Unnamed tributary to Tohickon Creek / 03195	6515-Operator of mobile home sites	Standard-Minor	Ron Isenhart
PA0045187	Richland Meadows MHP	Morgan Creek / 03184	6515-Operator of mobile home sites	Standard-Minor	William Lee
PA0051586	Clover D, Inc./Tohickon Family Campground	Tohickon Creek / 03110	7032-Sporting and recreational camps	Standard-Minor	
PA0050598	Bethel Baptist Church	Unnamed tributary to Tohickon Creek / 03181	8661-Religious organizations	Standard-Minor	Ralph Yarnell
PA0055395	Greentop MHP	Unnamed tributary to Tohickon Creek / 03188	6515-Operator of mobile home sites	Standard-Minor	Eleanor and George Roeder
PA0053929	Barryway Enterprises	Unnamed tributary to Tohickon Creek / 03112	4952-Sewerage systems	Standard-Minor	
PA0054704	Tri-county Respite	Unnamed tributary to	8099-Health and allied	Standard-Minor	Anne Mills

Permit ID	Facility Name	Receiving Stream/Code	SIC-Type	Permit Type	Responsible Party
		Tohickon Creek / 03173	services		
PA0053201	Royann Diner	Threemile Run / 03168	5812-Eating places	Standard-Minor	Ann D. Smith
PA0053015	Country Place Restaurant	Unnamed tributary to Tohickon Creek / 03170	5812-Eating places	Standard-Minor	Joseph Werner
PA0052787	Quakertown United Mennonite Church	Tohickon Creek / 03110	8661-Religious organizations	Standard-Minor	Raymond W. Schultz
PA0058017	Daniel F. Rufe	Haycock Creek / 03156		Standard-Minor	
PA0051993	Giambrone Enterprises	Tohickon Creek / 03195		Standard-Minor	
PA0058203	Peter's Clay Pots	Tohickon Creek / 03195		Standard-Minor	
PA0054364	Freedom Valley Girl Scouts	Tohickon Creek / 03110		Standard-Minor	
PA0058548	Keelersville Club STP	Threemile Run / 03170		Standard-Minor	

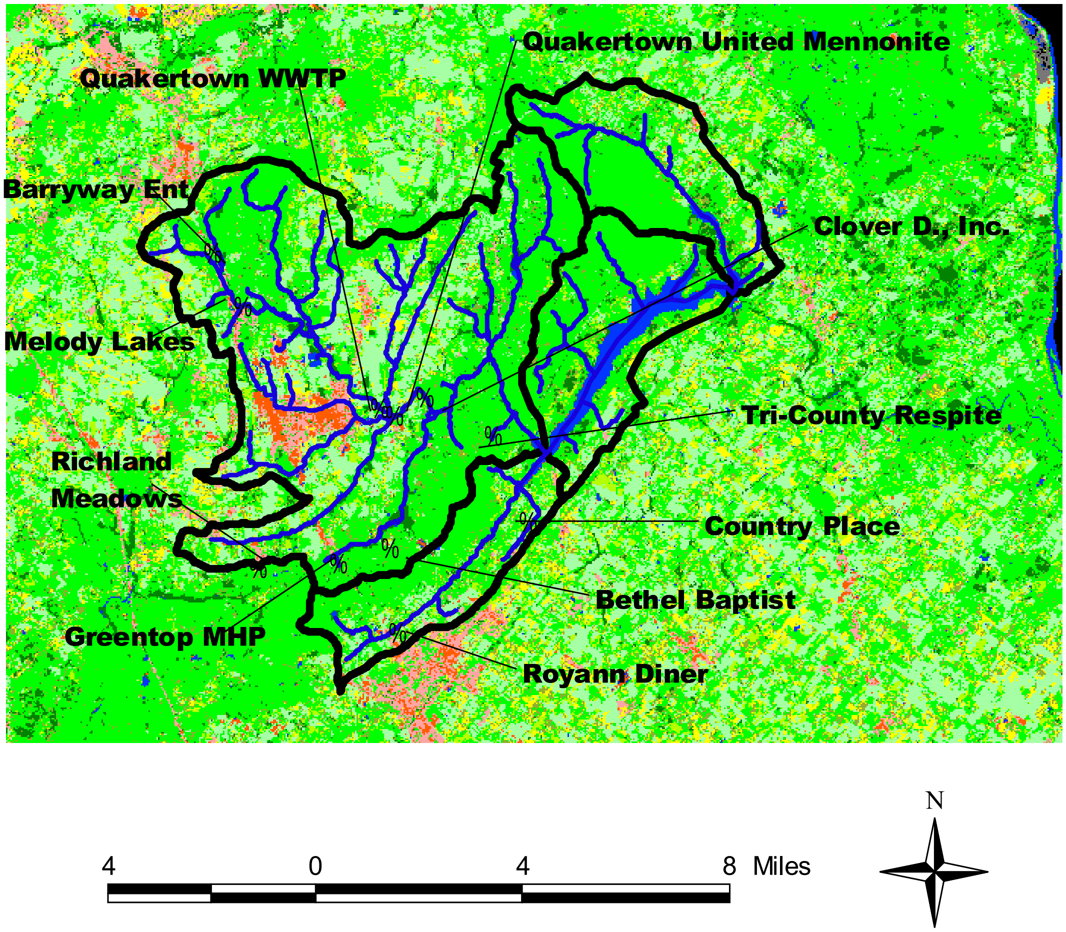


Figure 2-4. Location of point sources in Lake Nockamixon watershed

2.2.2 Discharge Monitoring Report Data

The Pennsylvania DEP identified and provided discharge monitoring report data for all 11 point source dischargers within the Lake Nockamixon watershed. The DMR data consisted of effluent limitations and reported average monthly values for flow, total phosphorus, carbonaceous biochemical oxygen demand, and dissolved oxygen from 1997 through 2002. Ammonia nitrogen data were also available for the Quakertown Waste Water Treatment Plant (WWTP).

2.3 Nonpoint Sources

In addition to point sources, nonpoint sources may also contribute to water quality impairments in the Lake Nockamixon watershed. Nonpoint sources represent contributions from diffuse, non-permitted sources. Typically, nonpoint sources are precipitation driven and occur as overland flow that carries pollutants into streams. However, nonpoint sources also include non-precipitation driven events such as contributions from groundwater, septic systems, or direct deposition of pollutants from wildlife and livestock.

2.3.1 Septic Systems

Septic systems also have the ability to contribute nutrient loads to the Lake Nockamixon watershed. Information regarding the number and magnitude of septic systems in Bucks County is derived from the 1990 Census tract survey.

2.3.2 Groundwater Nutrient Contributions

Recent USGS and Pennsylvania DEP data were used to create a statewide map of nitrogen and phosphorus concentrations in groundwater. The data are based on spatial relationships between nitrogen concentration, rock type, and land use. When developing the subsurface nutrient loads, an area-weighted is calculated and scaled to better represent subsurface nutrient concentrations in a given watershed. The nutrient load is also dependent on baseflow.

2.4 Land Use

Land use information from the Multi-Resolution Land Characterization (MRLC) completed in 1992 for Lake Nockamixon was available. The MRLC is a consortium of federal government agencies acting together to acquire satellite imagery for various environmental monitoring programs. One program that resulted from the MRLC effort is the National Land Cover Data (NLCD) program, which used images acquired from LANDSAT's thematic mapper sensor, as well as ancillary data sources, to produce a national land cover data set. The MRLC data are used to develop watershed loads for phosphorus and nitrogen. Table 2-6 contains land use information for the 4 subwatersheds that drain to Lake Nockamixon. Updated land use data from the Gap Analysis Program (GAP) are not available for this region of Pennsylvania. Figure 2-5 below shows the land use distribution in the Lake Nockamixon watershed.

Table 2-6. Land Uses in the Lake Nockamixon Watershed (in acres)

Land Use	Tohickon Creek	Threemile Run	Haycock Creek	Direct Drainage	Total
Water Bodies	331.05	120.42	212.19	1,214.83	1,878.49
Low development	975.15	132.86	22.89	13.56	1,144.46
High Development	753.26	57.76	23.33	27.56	861.91
Hay/Pasture	749.04	80.43	148.42	41.57	1,019.46
Cropland	7,762.96	1,171.07	1,086.27	830.49	10,850.79
Coniferous forest	389.97	98.64	226.63	293.87	1,009.11
Mixed forest	1,057.41	244.83	340.39	288.09	1,930.72
Deciduous forest	14,996.31	3,229.5	4,192.45	4,253.59	26,641.85
Woody wetland	940.47	40.21	43.1	44.01	1,067.79
Emergent wetland	162.75	11.33	15.78	21.12	210.98
Quarry	0	0	0	0	0
Coal Mine	0	0	0	0	0
Beaches	0	0	0	0	0
Transitional land	26.68	0.67	3.78	0	31.13
Unpaved Roads	7.28	5.07	5.76	3.05	21.16
Total	28,122.33	5,192.81	6,320.99	7,031.75	46,667.88

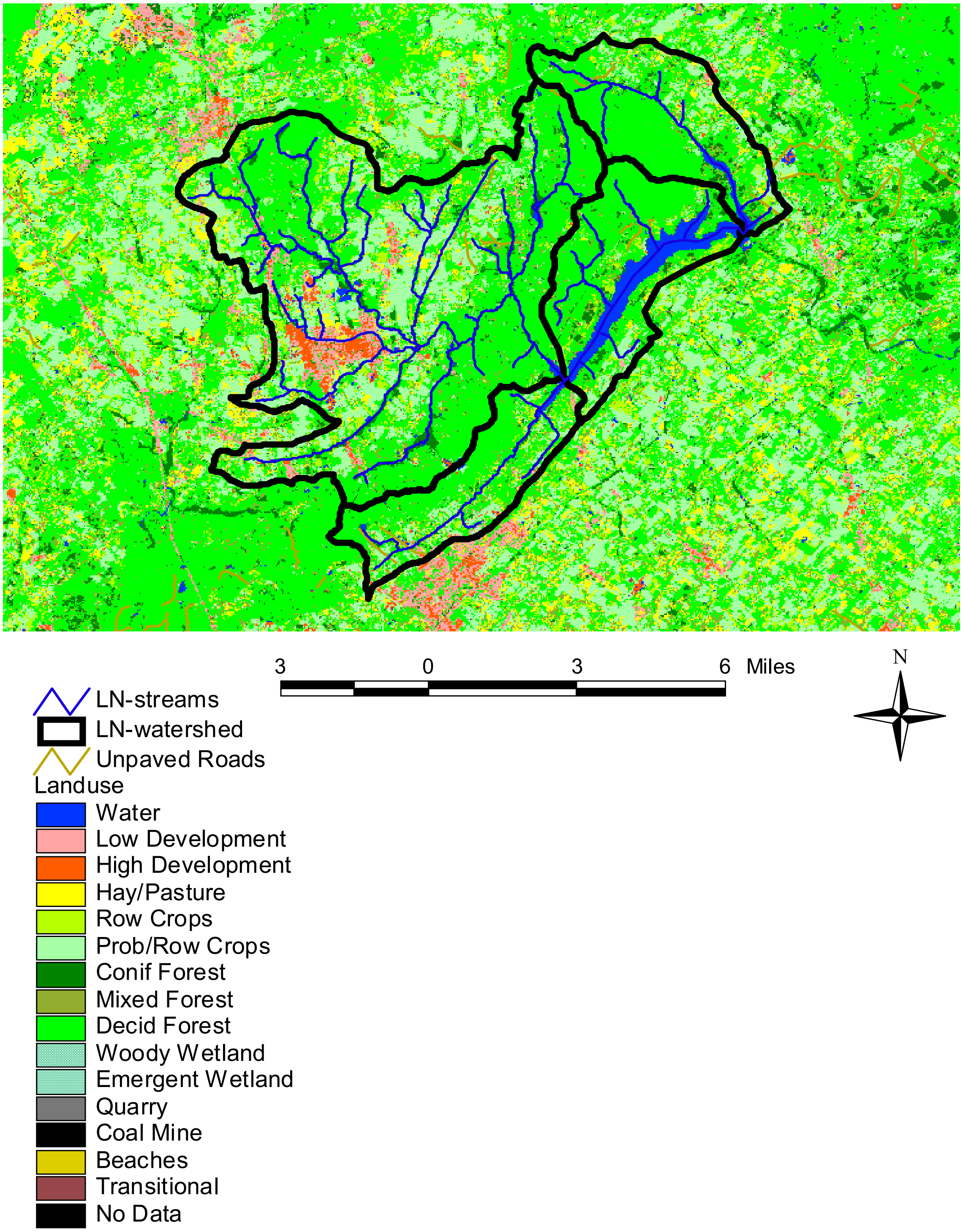


Figure 2-5. Land uses in the Lake Nockamixon watershed.

2.5 Meteorological Data

Because nonpoint source pollution is rainfall driven, precipitation data are necessary to assess the in-stream water quality affected by different land uses. The Sellersville weather station is located approximately 7.25 miles west of Lake Nockamixon, whereas the Palm 3SE station is about 12.5 miles west. In addition, the Allentown WSO Airport station and Graterford 1E stations are 16.5 and 17.5 miles, respectively, from Lake Nockamixon. Weather data from the Allentown WSO AP will be used for TMDL development for the Lake Nockamixon watershed (Figure 2-6). The Allentown WSO station is being used because the dataset provides 100 percent coverage, as opposed to other stations which provide less than 100 percent coverage. This particular Allentown WSO dataset ends on December 31, 2000; however, the National Climate Data Center (NCDC) Unedited Local Climatological Data system contains hourly weather observations at the Allentown WSO from 1996 through the present. The NCDC data were used to extend the weather dataset through April 2002. Table 2-7 below contains information for Sellersville and Palm 3SE stations.

Table 2-7. Meteorological Stations

Station ID	Station Name	State	Data Begin Date	Data End Date	Percent Coverage	Lat.	Long.	Elev.
PA 6681	Palm 3SE	PA	1/1/1971	12/30/2000	93	N40:38:33	W075:50:00	300
PA7938	Sellersville	PA	5/1/1948	12/31/2000	81	N40:35:88	W075:32:22	340
PA3437	Graterford 1E	PA	1/1/1976	12/31/2000	44	N40:23:33	W75:43:33	240
PA0106	Allentown WSO	PA	5/1/1948	12/31/2000	100	N40:65:08	W75:44:91	390

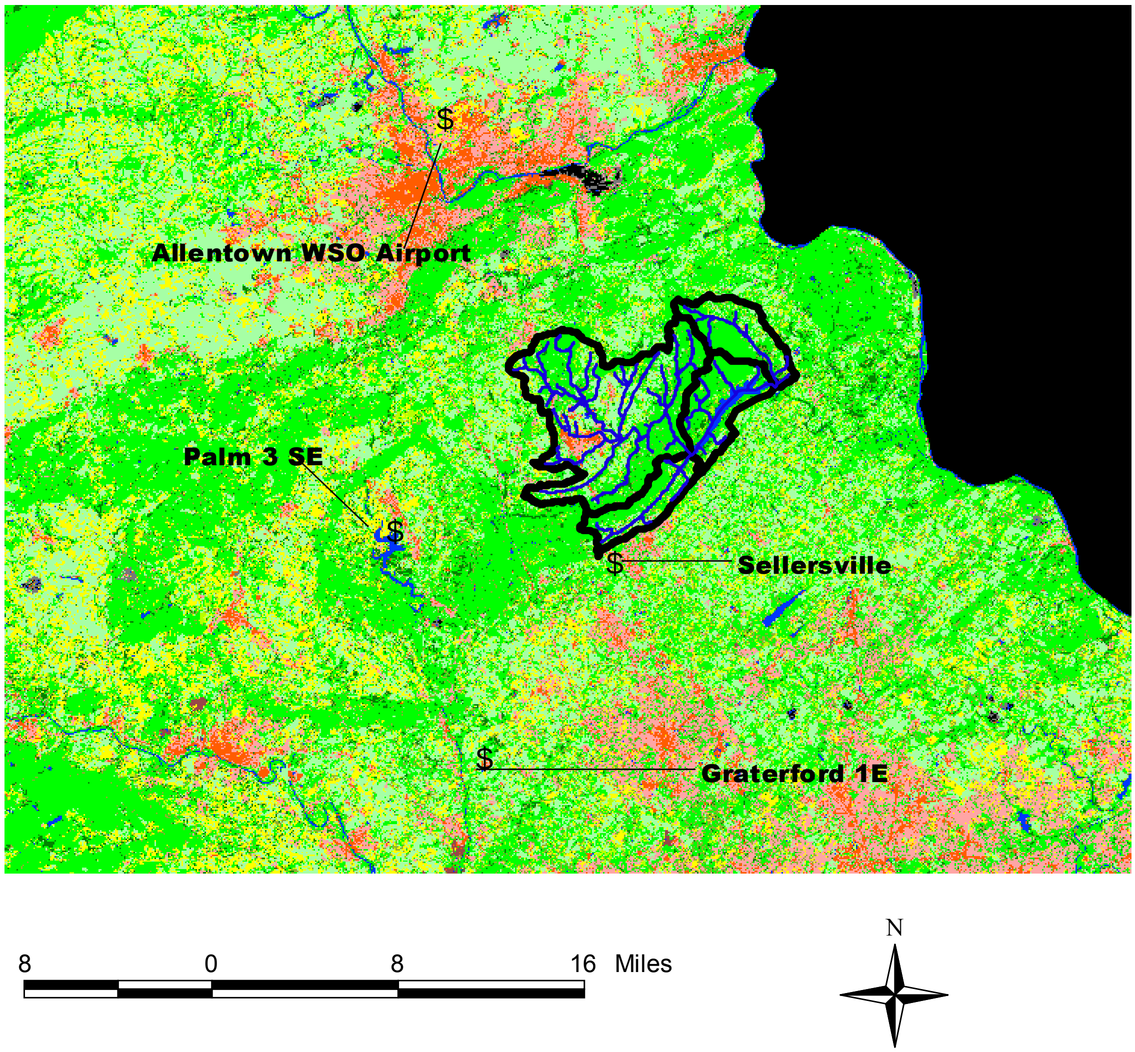


Figure 2-6. Location of weather stations near the Lake Nockamixon watershed.

The data referenced above represents all existing and readily available data for Lake Nockamixon. Considerable effort was expended to ensure that all relevant data were collected for this work effort. These data were analyzed and used as the basis for TMDL development to address nutrient and sediment impairments in Lake Nockamixon.

3.0 Technical Approach

Establishing the relationship between the in-stream water quality targets and source loadings is a critical component of TMDL development. It allows for evaluation of management options that will achieve the desired source load reductions. The link can be established through a range of techniques, from qualitative assumptions based on sound scientific principles to sophisticated modeling techniques. Ideally, the linkage will be supported by monitoring data that allow the TMDL developer to associate certain waterbody responses to flow and loading conditions

3.1 Technical Approach

. The objective of this section is to present the approach taken to develop the linkage between sources and in-lake response for TMDL development in the Lake Nockamixon watershed. Important processes and issues which impact the technical approach are described below.

3.1.1 Water Quality Endpoints

A key step in the development of technically appropriate TMDLs is to specify the numeric water quality endpoint or target. As previously mentioned, Pennsylvania does not have numeric water quality criteria for nutrients or sediment. General water quality criteria will be interpreted to develop acceptable water quality endpoints to support the designated uses of Lake Nockamixon. The approach to address nutrient impairments is to improve the trophic status of Lake Nockamixon from hyper-eutrophic to mesotrophic based on achieving an in-lake chlorophyll-a concentration of 10 ug/L. Chlorophyll-a is easy to measure, a valuable surrogate for algal biomass, and 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)). Pennsylvania believes that achieving an in-lake chlorophyll-a level of 10 ug/l through the control of phosphorus loading to the lake is consistent with applicable water quality standards for Lake Nockamixon.

3.1.2 Dominant Processes

The approach must also consider the dominant processes regarding pollutant loadings and in-stream fate. For the Lake Nockamixon watershed, primary sources contributing to perceived nutrient and sediment impairments include an array of nonpoint or diffuse sources as well as discrete point sources and permitted discharges. Loading processes for nonpoint sources or land-based activities are typically rainfall driven and thus relate to surface runoff and subsurface discharge to a stream. Permitted discharges may or may not be dependent on rainfall; however, they are controlled by permit limits. Key in-stream factors that must be considered include routing of flow, dilution, transport of nutrients, and nutrient cycling.

3.1.3 Scale of Analysis

Scale of analysis and waterbody type must also be considered in the selection of the overall approach. To determine lakewide nutrient and sediment impacts, the approach should have the capability to evaluate watersheds at multiple scales as well as lakes and reservoirs.

3.1.4 Technical Approach for Lake Nockamixon

Based on the considerations above, the overall approach to address nutrient and sediment impairments in Lake Nockamixon includes a combination of watershed and lake water quality modeling. This approach will provide a hydrologic/nutrient/sediment loading budget from the watershed that can be linked to an in-lake water quality model to assess the nutrient and algal condition of the lake. The watershed model used in this study is the Generalized Watershed Loading Functions (GWLF) model (Haith and Shoemaker, 1987). GWLF modeling was accomplished using the ArcView Version of the Generalized Watershed Loading Function (AVGWLF), developed by the Environmental Resources Research Institute of the Pennsylvania State University in ArcView (GIS software). The AVGWLF 4.0.3 GIS software (ArcView) interface facilitates the development of model input data and provides additional functionality (Evans, B., *et al.*, 2001). The benefit of using AVGWLF is that the AVGWLF was customized to include Pennsylvania-specific data. Furthermore, the GWLF model has the ability to consider both nonpoint and point sources. Since the sediment output from AVGWLF represents the sediment load delivered to the lake, only the AVGWLF model is necessary to characterize sediment loads and potential impairments in Lake Nockamixon.

Analyzing and assessing nutrient impairment in Lake Nockamixon require both the AVGWLF watershed model and the BATHTUB lake water quality model. To account for the natural decay of pollutant loads from point sources before it enters the lake, a simple decay spreadsheet is applied to point source loads to more accurately assess the nutrient load to Lake Nockamixon. The lake model used for TMDL development 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, 1999). BATHTUB is used to simulate the fate and transport of nutrients and water quality conditions and responses to the nutrient load into the lake. The BATHTUB model has been cited as an effective tool for lake and reservoir water quality assessment and management, particularly where data are limited (Ernst et al., 1994).

3.2 Watershed Model - AVGWLF

The Lake Nockamixon watershed was further segmented into four distinct subwatersheds to represent nutrient and sediment loadings and resulting lake concentrations (Figure 3-1). Three of the subwatersheds represent the three major tributaries to Lake Nockamixon, which are Threemile Run, Haycock Creek, and Tohickon Creek. The final subwatershed represents the area surrounding Lake Nockamixon that drains directly into the lake including many of the smaller tributaries. Subwatersheds were predetermined by AVGWLF using the included GIS datasets and are based on USGS Digital Elevation Model data and the EPA RF3 stream coverage.

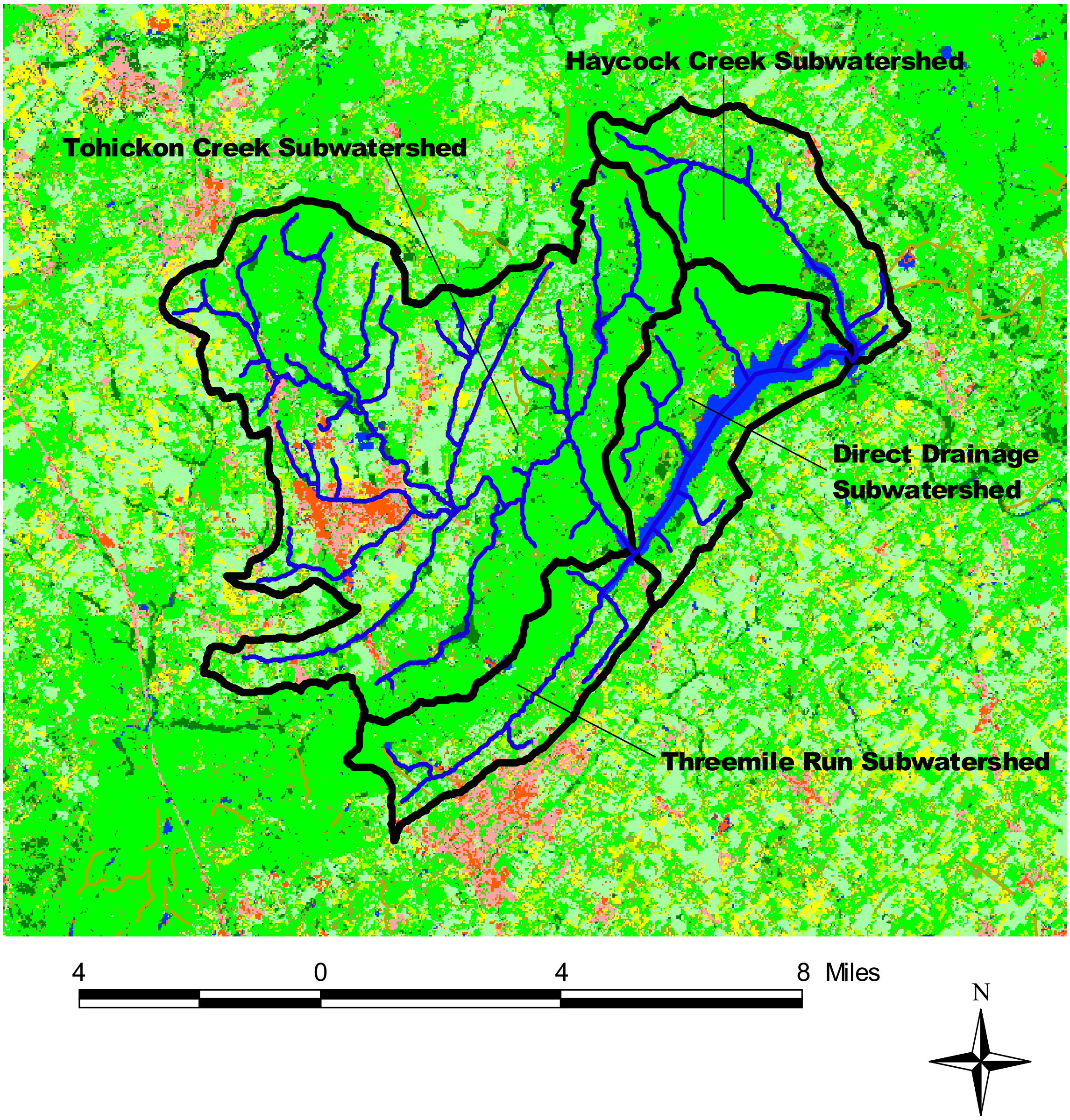


Figure 3-1. Lake Nockamixon subwatershed delineations.

The watershed model for Lake Nockamixon watershed was developed using the AVGWLF 4.0.3 ArcView interface and the GWLF model. The GWLF model, which was originally developed by Cornell University (Haith et al., 1992), provides the ability to simulate runoff, sediment, and nutrient loadings from watersheds given variable-size source areas (e.g., agricultural, forested, and developed land). It also has algorithms for calculating septic system loads, and allows for the inclusion of point source discharge data. GWLF is a continuous simulation model that uses daily time steps for weather data and water balance calculations. Monthly calculations are made for sediment and nutrient loads based on daily water balance totals that are summed to give monthly values.

GWLF is an aggregate distributed/lumped parameter watershed model. For surface loading, it is distributed in the sense that it allows multiple land use/cover scenarios. Each area is assumed to be homogeneous with respect to various attributes considered by the model. Additionally, the model does not spatially distribute the source areas, but aggregates the loads from each area into a watershed total. In other words, there is no spatial routing. For subsurface loading, the model acts as a lumped parameter model using a water balance approach. No distinctly separate areas are considered for subsurface flow contributions. Daily water balances are computed for an unsaturated zone as well as for a saturated subsurface zone, where infiltration is computed as the difference between precipitation and snowmelt minus surface runoff plus evapotranspiration.

GWLF models surface runoff using the Soil Conservation Service Curve Number (SCS-CN) approach with daily weather (temperature and precipitation) inputs. Erosion and sediment yield are estimated using monthly erosion calculations based on the Universal Soil Loss Equation (USLE) algorithm (with monthly rainfall-runoff coefficients) and a monthly composite of KLSCP values for each source area (e.g., land cover/soil type combination). The KLSCP factors are variables used in the calculations to depict changes in soil loss/erosion (K), the length/slope factor (LS), the vegetation cover factor (C), and the conservation practices factor (P). A sediment delivery ratio based on watershed size and a transport capacity based on average daily runoff are applied to the calculated erosion to determine sediment yield for each source area. Surface nutrient losses are determined by applying dissolved nitrogen and phosphorus coefficients to surface runoff and a sediment coefficient to the yield portion for each agricultural source area. Point source discharges can also contribute to dissolved loads to the stream and are specified in terms of kilograms per month. Manured areas, as well as septic systems, also can be considered. Urban nutrient inputs are all assumed to be solid phase, and the model uses an exponential accumulation and washoff function for these loadings. Subsurface losses are calculated using dissolved nitrogen and phosphorus coefficients for shallow groundwater contributions to stream nutrient loads, and the subsurface submodel considers only a single, lumped-parameter contributing area. Evapotranspiration is determined using daily weather data and a cover factor dependent on land use/cover type. Finally, a water balance is performed daily using supplied or computed precipitation, snowmelt, initial unsaturated zone storage, maximum available zone storage, and evapotranspiration values. All the equations used by the model can be found in the original GWLF paper (Haith and Shoemaker, 1987) and GWLF User's Manual (Haith et al. 1992 not in ref list).

For execution, the model requires three separate input files containing transport, nutrient, and weather-related data. The transport file (TRANSPRT.DAT) defines the necessary parameters for each source area to be considered (e.g., area size, curve number) as well as global parameters (e.g., initial storage, sediment delivery ratio, streambank erosion coefficient) that apply to all source areas. The nutrient file (NUTRIENT.DAT) specifies the various loading parameters for the different source areas identified (e.g., number of septic systems, urban source area accumulation rates, manure concentrations). The weather file (WEATHER.DAT) contains daily average temperature and total precipitation values for each year simulated.

3.2.1 GIS-Based Derivation of Input Data for the Watershed Model

The primary sources of data for the TMDL analyses were GIS formatted databases. The specially designed AVGWLF interface was used to generate the data needed to run the GWLF model (Evans et al., 2001).

When using the AVGWLF interface, the user is prompted to identify required GIS files and to provide other information related to "nonspatial" model parameters (e.g., beginning and end of the growing season, the months during which manure is spread on agricultural land, and the names of nearby weather stations). This information is subsequently used to automatically derive values for required model input parameters, which are then written to the TRANSPRT.DAT, NUTRIENT.DAT and WEATHER.DAT input files needed to execute the GWLF model. For use in Pennsylvania, AVGWLF has been linked with statewide GIS data layers such as land use/cover, soils, topography, and physiography, and it includes location-specific default information such as background nitrogen and phosphorus concentrations and cropping practices. Complete GWLF-formatted weather files are also prepared for 88 weather stations around the state up to year 1998. Table 3-1 lists the GIS datasets and provides an explanation of how they were used for development of the input files for the GWLF model.

Table 3-1. Statewide GIS datasets

Censustr	Coverage of census data including information on individual homes' septic systems. The attribute *susew_sept* includes data on conventional systems, and *su_other* provides data on short circuiting and other systems.
County	The county boundaries coverage lists data on conservation practices which provides C and P values for the Universal Soil Loss Equation (USLE).
Gwnback	A grid of background concentrations of nitrogen in groundwater derived from water well sampling.
Landuse5	Grid of the Multi-Resolution Land Characteristics (MRLC, 1991-1993) that has been reclassified into five categories. This is used primarily as a background.
Majoroad	Coverage of major roads. Used for reconnaissance of a watershed.
MCD	Minor civil divisions (boroughs, townships, and cities).
Npdes	A coverage of permitted point discharges. Provides background information and cross check for the point source coverage.

Padem	100-meter digital elevation model. This is used to calculate landslope and slope length.
Palumrlc	A satellite image-derived land cover grid (MRLC) that is classified into 15 different land cover categories. This data set provides land cover loading rates for the different categories in the model.
Pasingle	The 1:24,000 scale single-line stream coverage of Pennsylvania. Provides a complete network of streams with coded stream segments.
Physprov	A shapefile of physiographic provinces. Attributes *rain_cool* and *rain_warm* are used to set rainfall erosivity, and *gwrecess* is used to set recession coefficients.
Pointsrc	Major point source discharges with permitted nitrogen and phosphorus loads.
Refwater3	Shape file of reference watersheds for which nutrient and sediment loads have been calculated.
Soilphos	A grid of soil phosphorus loads that has been generated from soil sample data. Used to help set phosphorus and sediment values.
Smallsheds	A coverage of small watersheds for named streams at the 1:24,000 scale. This coverage is used with the stream network to delineate the desired watershed level.
STATSGO	A shape file of generalized soil boundaries. The attribute *mu_k* sets the k factor in the USLE. The attribute *mu_awc* is the unsaturated available capacity, and the *muhsg_dom* is used with land use/cover to derive curve numbers.
Strm305	A coverage of stream water quality as reported in Pennsylvania's 305(b) report. Current status of assessed streams.
Surfgeol	A shapefile of the surface geology used to compare watersheds with similar qualities.
Zipcode	A coverage of animal densities. Attribute *aeu_acre* helps estimate nitrogen and phosphorus concentrations in runoff in agricultural lands and over manured areas.
Weather Files	Historical weather files for stations around Pennsylvania to simulate flow.

Source: Evans et al., 2000

The weather files in the AVGWLF database contains weather data up to year 1998. The weather datasets used in GWLF models were extended through April 2002 by using the NCDC data at the Allentown WSO station.

As described above, the GWLF model provides the ability to simulate surface water runoff, as well as sediment and nutrient loads, from a watershed based on landscape conditions such as topography, land use/cover, and soil type. In essence, the model is used to estimate surface runoff and nonpoint source loads from different areas in the watershed. If point source discharges are present in the watershed, the corresponding nutrient loads are integrated into the GWLF model through the AVGWLF interface and these loads are added to the nonpoint source nutrient loads to develop the total nutrient loading from the subwatershed.

3.2.2 Critical Conditions and Seasonal Environmental Variation

The use of meteorological data ensures that TMDL development is consistent with the technical and regulatory requirements of 40 CFR Section 130. These regulations require TMDLs to consider critical environmental conditions and seasonal environmental variations. The requirements are designed to simultaneously ensure that water quality is protected during times when it is most vulnerable and take into account changes in streamflow and loading characteristics as a result of hydrological or climatological variations. These conditions are important because they describe the factors that combine to cause violations of water quality standards and can help identify necessary remedial actions. Critical conditions in Lake Nockamixon include periods of increased nutrient and sediment loading to the lake, typically from October through March during higher seasonal stream flow and precipitation. Another critical condition occurs when the lake experiences higher temperatures and increased algal growth typically from April through September. Nutrient loads may not be significant during this period because of reduced stream flow and precipitation, however, the concentration of nutrients in the lake may be elevated, causing impairments. The AVGWLF model was executed from April 1993 through May 2002 and appropriately considers both critical environmental conditions and seasonal environmental variation.

Table 3-2 illustrates the descriptive statistics for both precipitation at the Allentown WSO station and streamflow at the USGS gage station 01459500. These statistics help support the conclusion that critical conditions and seasonal environmental variations are appropriately addressed. Over the 9-year simulation period, a range of precipitation and stream flow conditions were represented. Total precipitation for 2 of the simulation years was well above the 80 percent occurrence probability based on data from 1935 through 1996. Three years were very close to average while the remaining 4 years were below the average. In terms of stream flow, there are 2 years where streamflow was well above the 80 percent occurrence probability. The remaining seven years are very close to average stream flow conditions based on data from 1935 through 2000.

Table 3-2 Descriptive Statistics for Precipitation and Stream Flow

Year	Begin Month	Ending Month	Total Annual Precipitation (cm/year)	Mean Annual Streamflow (cfs)
1	April 1993	March 1994	141.7	
2	April 1994	March 1995	100.1	237.49
3	April 1995	March 1996	106.0	137.91
4	April 1996	March 1997	134.8	151.44

Year	Begin Month	Ending Month	Total Annual Precipitation (cm/year)	Mean Annual Streamflow (cfs)
5	April 1997	March 1998	97.6	263.48
6	April 1998	March 1999	96.1	133.49
7	April 1999	March 2000	90.0	148.78
8	April 2000	March 2001	105.1	133.53
9	April 2001	March 2002	82.7	139.99
Descriptive Statistics for Total precipitation at Allentown WSO Airport Station (cm/year)				
Average (1993-2002)				105.99
Average (1935 - 1996)				111.64
Minimum (1935-1996) (occurred 1980)				72.62
Maximum (1935-1996) (occurred 1952)				178.51
Percentile of selected precipitation values - 20%				98.09
Percentile of selected precipitation values - 40%				106.7
Percentile of selected precipitation values - 60%				115.5
Percentile of selected precipitation values - 80%				126.44
Descriptive Statistics for Total Stream Flow at USGS Gage Station 01459500				
Average (1993-2002)				140.9
Average (1935 - 2000)				149.1
Minimum (1935-2000) (occurred 1965)				42.2
Maximum (1935-2000) (occurred 1996)				294.0
Percentile of selected precipitation values - 20%				109.4
Percentile of selected precipitation values - 40%				127.6
Percentile of selected precipitation values - 60%				153.2
Percentile of selected precipitation values - 80%				187.4

3.2.3 Background Pollutant Contributions

Federal regulations at 40 CFR Section 130 require TMDLs to consider the impact of background pollutant contributions. The AVGWLF model adequately considers background pollutants by including nutrient contributions from groundwater as well as natural and forested areas. The groundwater component includes both interflow and baseflow contributions. Nutrient contributions from septic systems, background nutrient concentrations in soil, and nutrients from manure application are also considered by AVGWLF.

3.2.4 Explanation of Important Model Parameters

In the GWLF model, the nonpoint source load calculation is affected by terrain conditions, such as the amount of agricultural land, land slope, soil erodibility, farming practices used in the area, and by background concentrations of nutrients (nitrogen and phosphorus) in soil and groundwater. Various parameters are included in the model to account for these conditions and practices. The parameters are explained in detail in Appendix A.

Other less important factors that can affect sediment and nutrient loads in a watershed are also included in the model. More detailed information about these parameters and those outlined above can be obtained from the GWLF User's Manual (Haith et al., 1992). Pages 15 through 41 of the manual provide specific details that describe equations and typical parameter values used in the model.

3.2.5 Hydrology Calibration and Validation

The model hydrology calibration and validation processes involved comparing the observed and simulated flow data. However, as described in Section 2.1.1, there are no active USGS gages in the Lake Nockamixon watershed. Nor is there any information available regarding historical stream flow data. One station, USGS gage 01459500, was found and is located approximately 3.5 miles downstream from the outlet site of Lake Nockamixon into the Tohickon creek near Pipersville, Pennsylvania. Data from this site begin July 1935 and continue through the present.

Using the input files created from the AVGWLF interface, GWLF predicted overall water balances for the watershed drained by gage 01459500. The predicted water balances (i.e. stream flow) were compared to observed water balance data from the USGS gage station. The hydrologic parameters of the GWLF model for Lake Nockamixon watershed were then adjusted until the predicted water balance compared favorably to observed water balances. The hydrologic model was calibrated from 4/1/1993 through 4/1/1994 and validated from 4/2/1994 through 9/31/2001. Monthly observed and simulated flow volumes are shown in Figure 3-2. The accuracy of the calibration and validation is indicated by the R^2 value, which was 0.75. This indicates a strong, positive correlation between simulated and observed data.

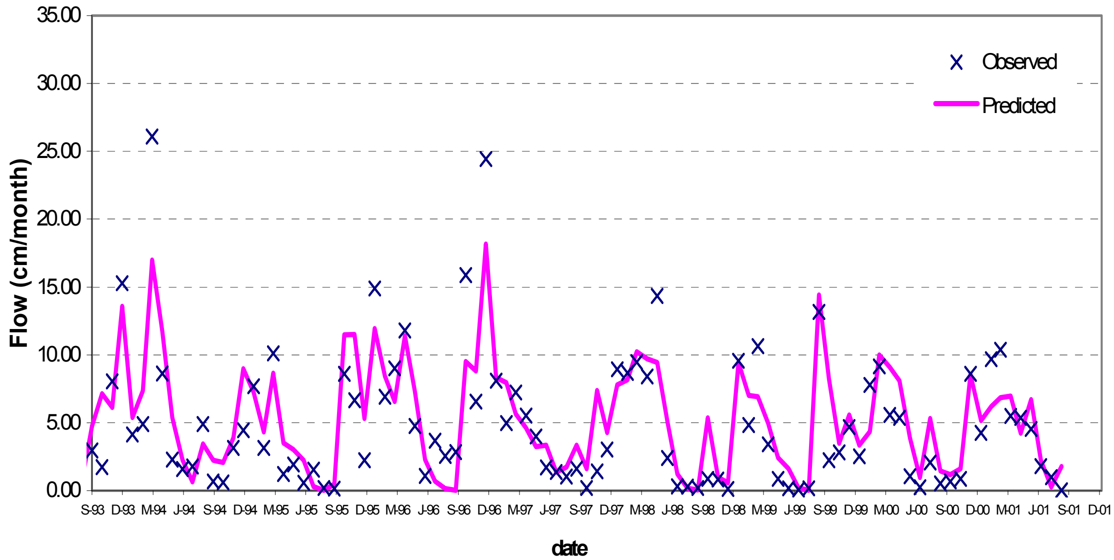


Figure 3-2. Hydrology calibration plot for USGS gage 01459500

As mentioned, the Lake Nockamixon watershed was subdivided into four subwatersheds. Flow, nutrient, and sediment loading data were not available for any of the tributaries draining into Lake Nockamixon. To overcome the lack of data, the hydrologic parameters from the GWLF model calibrated at USGS gage station 01459500 were used to develop the GWLF model. Considering that the watershed drained by USGS gage station 01459500 and the Lake Nockamixon subwatersheds share similar geomorphology, hydrology, and land use characteristics, this surrogate calibration and validation method is appropriate.

3.2.6 Nonpoint Source Loads Estimation Using the GWLF Model

The hydrologically calibrated GWLF model was used to simulate the sediment and nutrients loads from the four subwatersheds in the Lake Nockamixon watershed. The simulation period extended from April 1993 through March 2002. AVGWLF provides hydrologic and nutrient outputs based on water year extending from April through March. Data from April 1996 through March 2001 is shown due to the fact that point source information was available from January 1997 through December 2001. The simulated nonpoint source monthly loads of nutrients from April 1996 through March 2002 for each subwatershed are presented in Appendix B. The monthly loads calculated during this period will be used to develop input data for the BATHTUB model to investigate the nutrient and algal conditions of the reservoir.

3.2.7 Point Source Loads Estimation

Point source loads were calculated based on Discharge Monitoring Report data provided by Pennsylvania DEP. The DMR data included monthly average concentrations as well as effluent limitations for total phosphorus and flow. These two parameters were used to calculate the monthly phosphorus load from each point source. Depending on the location of the point source, the monthly phosphorus loads were combined with the nonpoint source loads as determined by AVGWLF to determine the total subwatershed phosphorus load.

As mentioned in Section 1, soluble inorganic phosphorus is generally considered most important in terms of algal growth. However, the point source data gives only total phosphorus. In order to determine the total phosphorus speciation in point source discharges (i.e., between organic particulate and soluble inorganic), an empirical ratio of 0.92 dissolved to total phosphorus is applied to the total phosphorus load from Quakertown WWTP only, to calculate soluble inorganic phosphorus. This ratio is based on empirical data from wastewater treatment plants with tertiary treatment. The load from all other point sources was insignificant compared to Quakertown WWTP, so speciation considerations were not applied.

All the point sources in the Lake Nockamixon watershed are located on tributaries to Lake Nockamixon. The closest point source is approximately 0.5 stream miles from Lake Nockamixon while the farthest is located approximately 9.75 stream miles. Quakertown WWTP, the largest point source contributor of total phosphorus averaging more than 90 percent of all point source loads of total phosphorus from April 1996 to March 2002, is located approximately 4.5 miles upstream of Lake Nockamixon on Tohickon Creek. To appropriately account for the fate and transport (i.e. natural decay and transformation) of nutrients from point sources, a simple decay spreadsheet model was applied to all point source discharges. The spreadsheet takes into account the travel time and applies empirical equations to determine the amount of phosphorus from Quakertown WWTP that actually enters the lake. The amount of decay is based on the following equation:

$$e^{(-kt)}$$

where k = 0.084 and t = travel time from point of discharge to lake.

Travel time was determined from information provided in the Lake Nockamixon EPA Clean Lakes Program, Phase II Report submitted in November 1992 to the Bucks County Conservation District. The report was prepared by FX Browne Associates. The point source loads calculated from April 1996 through March 2002 are included in Appendix C (Tohickon Creek) and Appendix D (Threemile Run).

3.2.8 Significant Sources of Sediment and Phosphorus Loads to Lake Nockamixon

Following execution of the hydraulically calibrated and validated watershed model, the AVGWLF nutrient output was analyzed to characterize nutrient loads. Because point source data were only available from January 1997 through March 2002, the nutrient loads were analyzed from April 1996 through March 2002. The point source data were projected back 1 year by using the 1997 point source data to represent point source nutrient loads in 1996. This procedure was done because 1996 was an above average precipitation year and including this year in the analysis would add validity to the use of average nutrient loading conditions from nonpoint sources in the Lake Nockamixon watershed.

Table 3-3 displays information about nutrient loading based on AVGWLF model results from 1996 through 2002.

Table 3-3. Significant Nutrient Loads to Lake Nockamixon from AVGWLF

Source	Total Phosphorus (lb/year)	Percent of total load	Percent of total NPS load
Total Load	9,614.59	100	
Total Point Source Load	2,520.91	26.21	
Total Nonpoint Source Load	7,093.68	73.78	
Largest Individual NPS Sources			
Cropland and hay/pasture	3,985.42	41.45	56.18
Streambank	807.53	8.4	11.38
Groundwater	1,878.88	19.54	26.49
Septic Systems	279.51	2.9	3.94
Largest Individual Point Sources			
Quakertown WWTP	2,305.35	23.98	
All other point sources	215.56	2.24	

On average, based on AVGWLF results for 6 years, nonpoint sources contribute about 74% of the total phosphorus load and 100 percent of the total sediment load to Lake Nockamixon. Point sources contribute about 26% of the total phosphorus load, of which Quakertown WWTP in the Tohickon Creek watershed contributes about 24 percent of the total phosphorus load. In terms of nonpoint source phosphorus loads, cropland/hay/pasture and groundwater contribute approximately 41 percent and 19 percent, respectively, of the total phosphorus load.

3.3 Lake Nockamixon Water Quality Model

BATHTUB applies a series of empirical eutrophication models to morphologically complex lakes and reservoirs. The program performs steady-state water and nutrient balance calculations in a spatially segmented hydraulic network that accounts for advective and diffusive transport, and nutrient sedimentation. Application of BATHTUB is limited to steady-state evaluation of relationships between nutrient-loading, transparency and hydrology, and eutrophication responses. Eutrophication-related water quality conditions (total phosphorus, total nitrogen, chlorophyll a, transparency, and hypolimnetic oxygen depletion) are predicted using empirical relationships derived from assessment of reservoir data (Walker, 1999).

3.3.1 Model Setup

Lake Nockamixon was divided into five segments (Figure 3-3). Characteristics such as surface area, length, mean depth, mixed layer depth, and hypolimnetic depth for each segment are listed in Table 3-4. Segmentation provides the ability to predict chlorophyll-a concentrations with greater spatial resolution. This also allows the model to more accurately represent the physical characteristics (i.e., bathymetry, volume, reservoir shape) of the lake.

The BATHTUB model uses the flow and nutrient loads estimated by the GWLF watershed model as input data to determine chlorophyll-a concentrations in the lake. Each model segment received inflows from the subwatersheds that delivered water and nutrients to that segment. The contributing subwatersheds are illustrated in Figure 3-1. The contribution of the direct drainage subwatershed to segments 3, 4, and 5 was apportioned since this subwatershed affects all three segments.

Table 3-4. Characteristics of the Five Segments of Lake Nockamixon Modeled by BATHTUB

Characteristics	Segment				
	1	2	3	4	5
Surface area, km2	0.138	0.151	3.367	0.167	0.147
Length, km	0.81	1.08	8.33	1.67	0.23
Mean depth, m	5	5	13.3	5	18
Mixed layer depth, m	5	5	7	5	7
Hypolim. depth, m	0	0	6.3	0	11
Tributary inflow source	Tohickon Crk	Threemile Run	Direct	Haycock	-
Outflow routed to segment number	3	3	5	5	Outflow
Water quality sampling station (figure 2-3)	N/A	N/A	2*	N/A	3

* only has 1995 WQ data

It is important to recognize how the model is segmented to represent Lake Nockamixon. Segments 1, 2, and 4 represent transitional areas where tributaries flow into the lake. These transitional areas resemble slow-moving, wide, shallow rivers as opposed to lakes or reservoirs. It is necessary to segment these areas in order to properly represent actual conditions in the lake. Segments 3 and 5 represent the main body of Lake Nockamixon and correspond to locations of existing lake water quality data. Furthermore, compliance with the water quality objective for nutrients will be determined in segments 3 and 5.

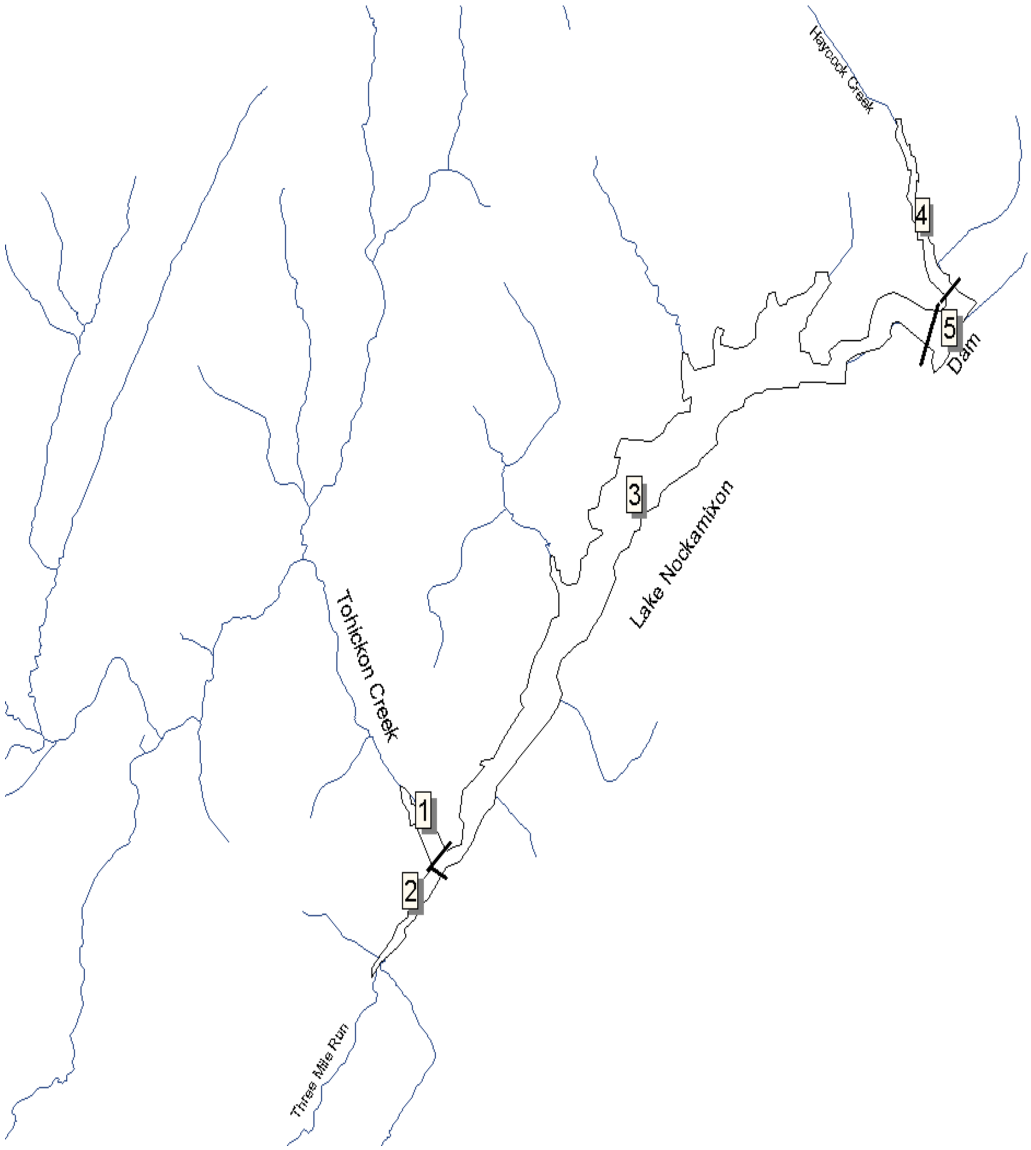


Figure 3-3. Segmentation of the Lake Nockamixon BATHTUB model

3.3.2 Critical Conditions and Seasonal Environmental Variation

Critical conditions and seasonal environmental variations are adequately accounted for in the AVGWLF model. In terms of the Lake Nockamixon BATHTUB model, critical conditions include periods of increased sunlight, temperature, and algal growth that typically occur from April through September (i.e the growing season). The BATHTUB model parameters, such as sunlight availability and chlorophyll-a flushing rates, help to address critical conditions. Furthermore, the model can be executed over an entire year or limited to the growing season.

3.3.3 Background Pollutant Contributions

The Lake Nockamixon BATHTUB model adequately considers background pollutant contributions by using observed nutrient concentrations from water quality monitoring data to set up initial concentrations in the lake. The data collected by Pennsylvania DEP during the TSI studies and the BCCD was used to characterize background nutrient concentrations in the water column of Lake Nockamixon.

3.3.4 Model Calibration and Verification

The model was calibrated using chlorophyll-a data from 2000 and by adjusting model options (Table 3-2) discussed in the BATHTUB User's Manual (Walker, 1999). The annual water and nutrients loads calculated from AVGWLF for year 2000 were used as inputs to BATHTUB. The model was executed from April through September 2000 and the predicted chlorophyll-a concentrations were compared with observed chlorophyll-a and total phosphorus concentrations. The observed data used for calibration were collected by the Pennsylvania DEP as part of the TSI studies performed in 1995, 1999, 2000, and 2001 at station 3 (see Figure 2-4).The model was tuned until the predicted seasonal chlorophyll-a and total phosphorus concentrations compared favorably with the observed seasonal chlorophyll-a and total phosphorus concentrations. Parameters that were important during calibration include dispersion rate, phosphorus calibration factor, and the chlorophyll-a flushing rate. Figure 3-4 shows the comparison of the model simulated results and the observed value of total phosphorus and chlorophyll-a concentrations. Following calibration, the robustness of the model was verified using year 1995 chlorophyll-a and total phosphorus data from the Pennsylvania DEP TSI studies. During this verification, data from the 1997 DMR's were used to represent point source contributions of nutrients to the watershed. As presented in Figure 3-5, the predicted results are in reasonable agreement with the observed values. After calibration and verification, the model were used to simulate the lake's responses to various TMDL allocation scenarios.

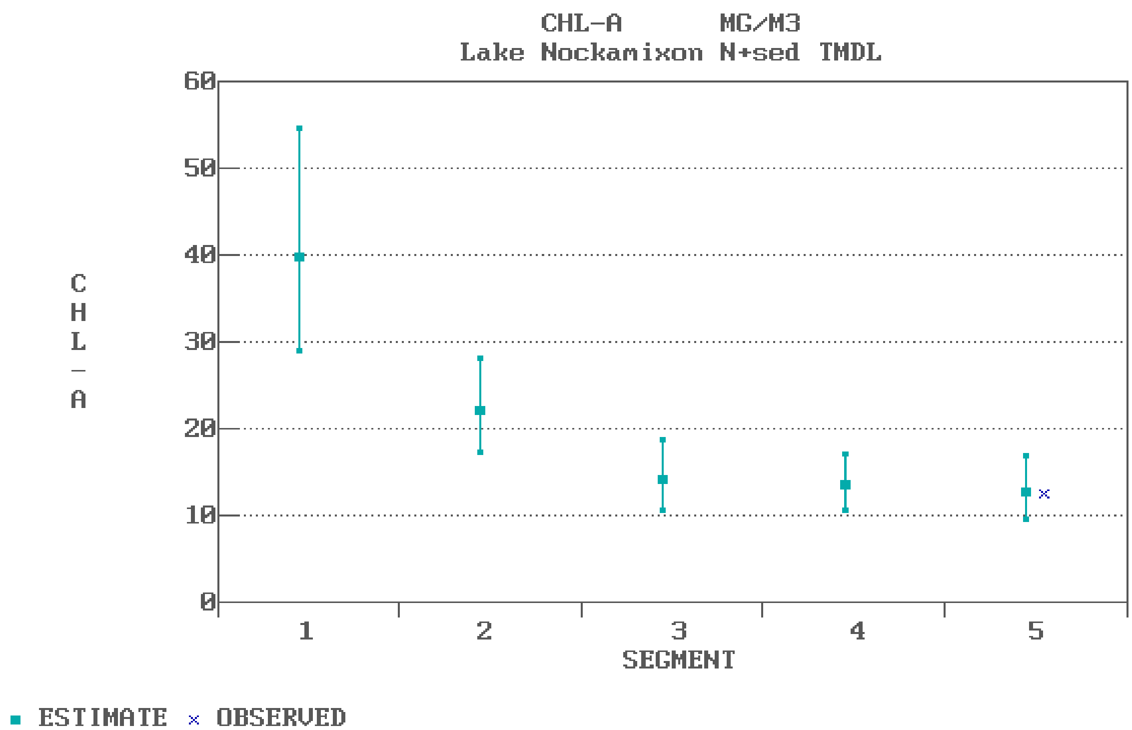
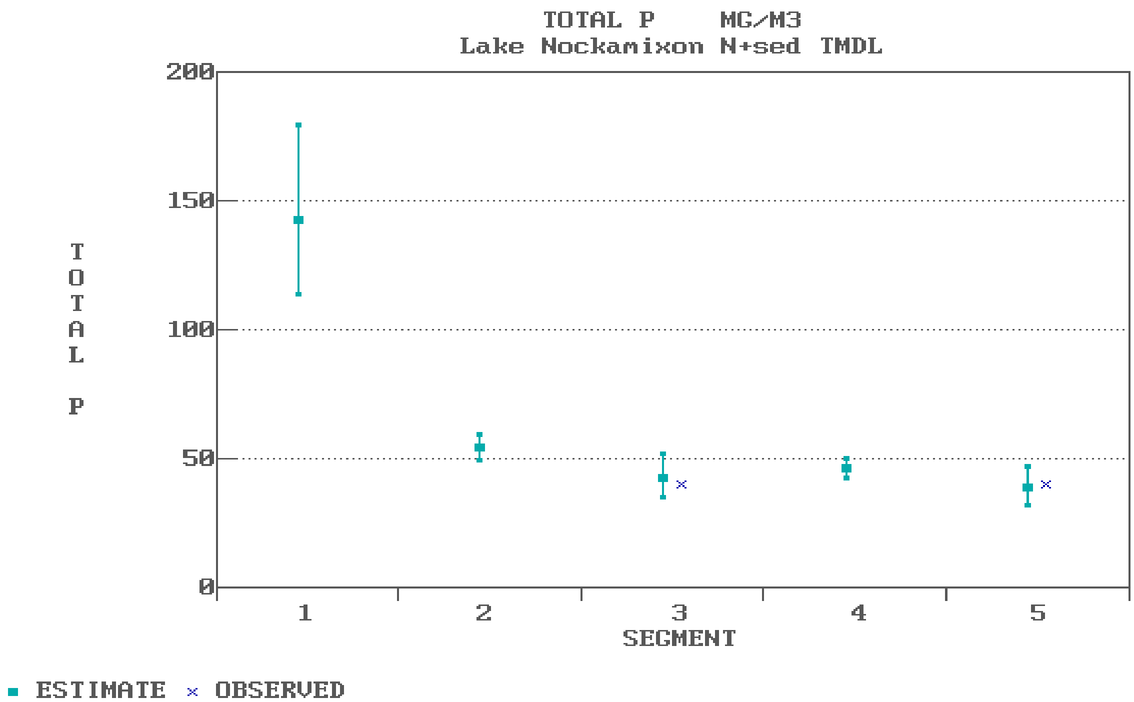


Figure 3-4. Calibration Plots for Lake Nockamixon BATHTUB Model



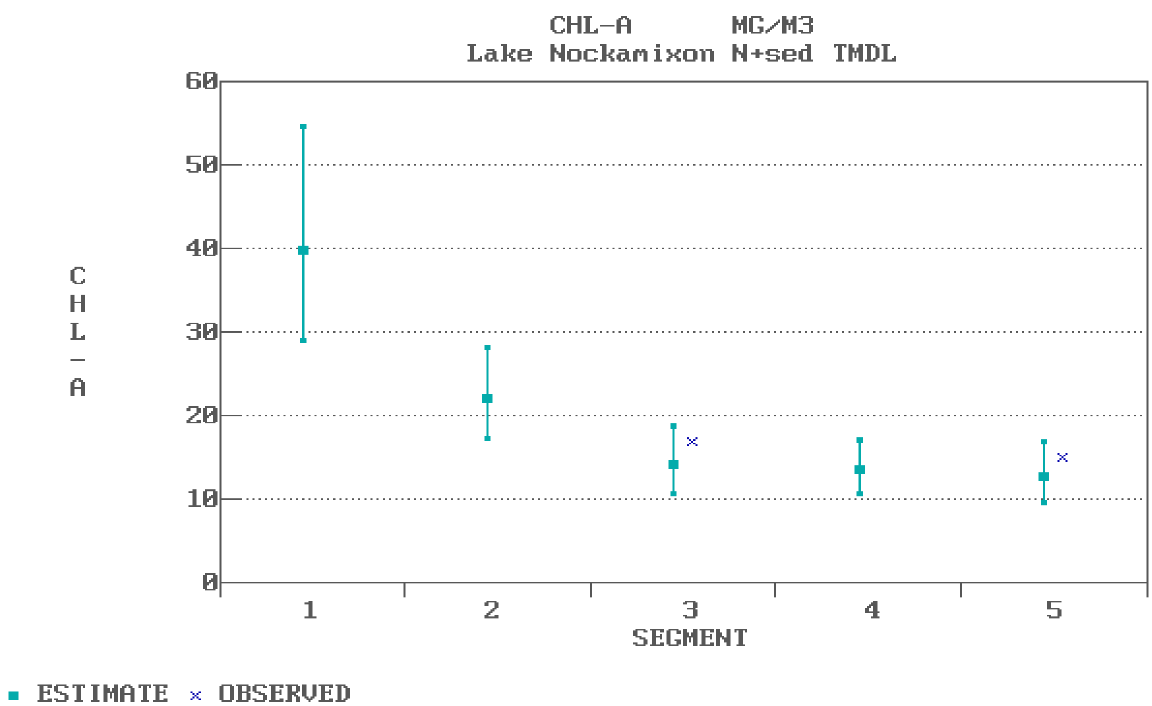


Figure 3-5. Verification plots for Lake Nockamixon BATHTUB model

Luxembourg, a minimum 100-year life span is selected as the comparative target.

The sediment accumulation to Lake Nockamixon is assessed using trap efficiency calculations. Trap efficiency refers to the ability of lakes and reservoirs to retain a portion of the sediment loading. This efficiency is expressed as the percent of sediment retained compared to the total incoming sediment. The factors that affect the efficiency of lakes and reservoirs to trap sediments include sediment particle size distribution, the lake hydraulic residence time, and the design and operation of the reservoir outlets. For large reservoirs, those with 10,000 acre-feet or more of storage capacity, the trap efficiency is 100 percent (ASCE, 1977). Lake Nockamixon contains approximately 39,900 acre-feet of storage capacity, therefore, the sediment loading and impact analysis is conducted assuming 100 percent trap efficiency.

The sediment loading analysis is conducted using two different scenarios. The first scenario analyzes the total sediment loading from the four subwatersheds in relation to the total lake storage capacity. The second scenario looks at the localized impact from each subwatershed in relation to the area where the stream or river enters the lake. These areas occur where higher energy, faster-flowing rivers and streams carrying sediments encounter lower energy, slow-flowing or still lake waters and are the sites of greatest sediment accumulation. The GIS datasets included in AVGWLF are used to determine the volume of the sediment accumulation areas. Figure 3-3 above delineates the sediment accumulation areas that correspond to each subwatershed based on BATHTUB segmentation. The depositional area for Tohikcon Creek corresponds to BATHTUB segment 1, Threemile Run depositional area corresponds to segment 2, and Haycock Creek depositional area corresponds to segment 4. For the direct drainage area of Lake Nockamixon, the sediment accumulation area is calculated by aggregating embayment areas associated with the smaller streams identified by the EPA RF3 stream dataset. The selected depositional locations are the areas most likely to create barriers for recreational uses. These areas are shown in Figure 4-1.

Sediment loading from each subwatershed is determined using the AVGWLF model. The maximum annual sediment loads predicted over the 6-year simulation period for each subwatershed are used for conservative purposes. The monthly sediment loads calculated by AVGWLF are presented in Appendix E. To determine the lake volume displaced by sediment loading from the watershed, literature-cited volume-weight measurements ranging from 31.1 lb/ft^3 to 59.9 lb/ft^3 are used. These volume-weight measurements are based on studies of various lakes across the nation (Brune, 1953). Both the lower and upper range of measurements are used. Table 4-1 presents the relevant information used to conduct the sediment analysis.

Table 4-1. Displaced Lake Volume from Sedimentation and Life Span of Lake Nockamixon

Watershed/ Depositional area	Depositional-area volume (acre-ft)	Annual Sediment load (lb/yr)	Sediment volume-weight measurements (lb/ft^3)	Lake volume displaced (acre-ft/yr)	Depositional Area Life Span (yr)
Tohickon Creek	755	4,255,819	31.1	3.141	240.3
Threemile Run	1,010	192,864	31.1	0.142	7,094

Watershed/ Depositional area	Depositional-area volume (acre-ft)	Annual Sediment load (lb/yr)	Sediment volume-weight measurements (lb/ft^3)	Lake volume displaced (acre-ft/yr)	Depositional Area Life Span (yr)
Haycock Creek	1,350	201,928	31.1	0.149	9,057
Direct Drainage	3,115	105,184	31.1	0.078	40,119
Lake Nockamixon	39,900	4,755,797	31.1	3.511	11,365
[redacted]					
Tohickon Creek	755	4,255,819	59.9	1.631	462
Threemile Run	1,010	192,864	59.9	0.074	13,664
Haycock Creek	1,350	201,928	59.9	0.077	17,444
Direct Drainage	3,115	105,184	59.9	0.040	77,271
Lake Nockamixon	39,900	4,755,797	59.9	1.823	21,890

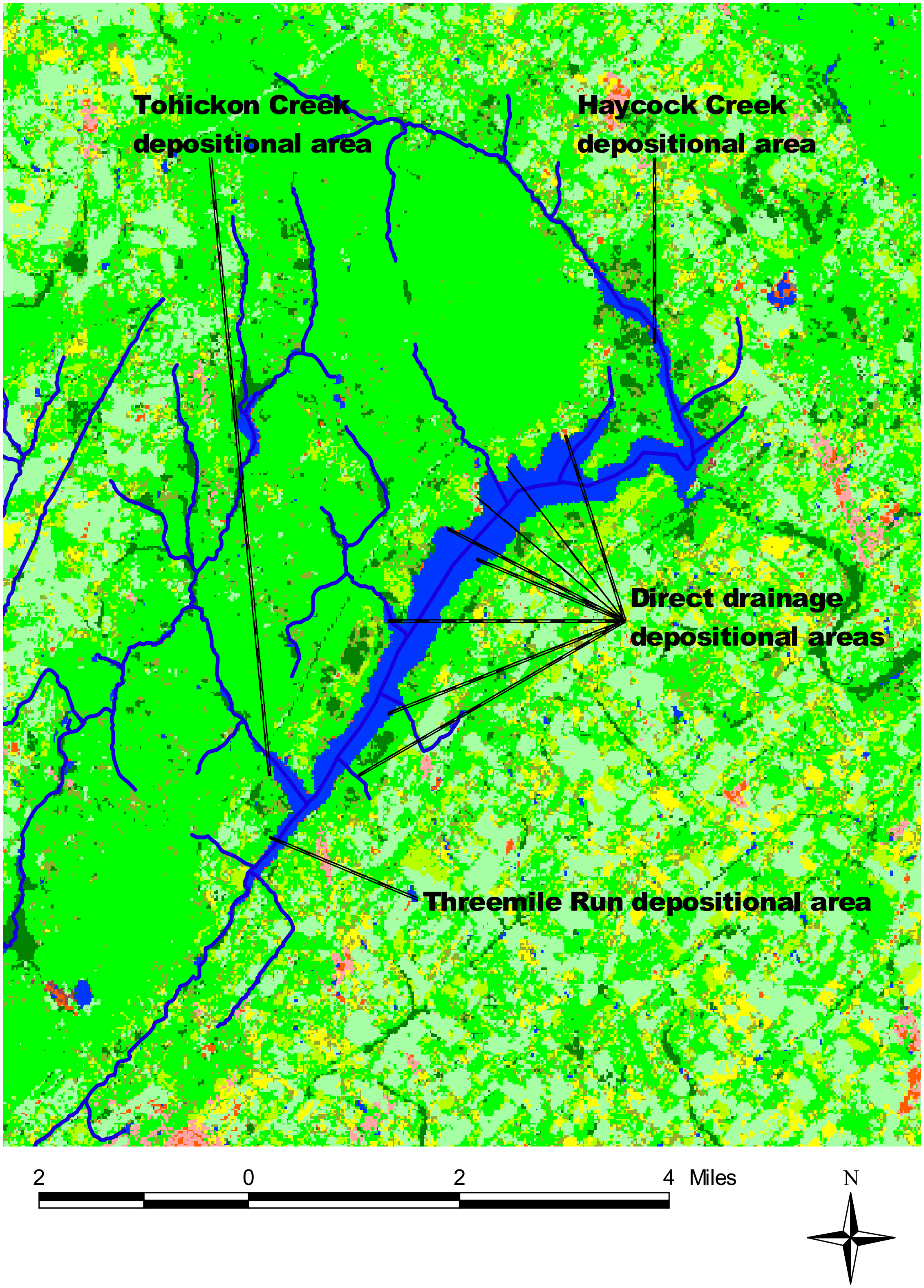


Figure 4-1. Sediment depositional areas in Lake Nockamixon.

The results presented in Table 4-1 show the lake volume displaced per year based on the annual sediment load. The lake volume is based on the depositional area identified using GIS datasets and represents the area that receives sediment loading from streams or rivers. The depositional area is divided by the lake volume displaced per year to determine the estimated number of years until that depositional area is filled with sediment. Using the lower and upper range of sediment volume-weight measurements and the maximum annual sediment loading predicted over the 6-year simulation period, the minimum estimated life span of the individual depositional areas ranges from 240 to 462 years. Lake Nockamixon is predicted to have a life span ranging from almost 11,000 to 21,000 years.

Based on the sediment loading analysis results presented in Table 4-1 and the absence of evidence documenting in-lake use impairments or other in-lake problems due to elevated suspended solids, it is not necessary to develop a TMDL for sediments to address suspended solids impairments in Lake Nockamixon.

4.2 Phosphorus Loading Analysis

The calibrated and validated AVGWLF and BATHTUB models were used to develop the phosphorus TMDL that would attain and maintain water quality standards for Lake Nockamixon. TMDL development was performed using baseline conditions for point and nonpoint source total phosphorus loads. Baseline conditions for nonpoint sources are calculated by determining the average total phosphorus load over a 6-year simulation period from April 1996 through March 2002. Average pollutant loading characteristics for nonpoint sources are more representative of the long-term conditions experienced in Lake Nockamixon. Long-term conditions provide consistency with critical conditions and seasonal environmental variations requirements.

Baseline conditions for point source total phosphorus loads are set equal to permit limits for total phosphorus and flow. This represents the maximum allowable total phosphorus load that the point source may discharge and still comply with NPDES permit requirements. Thirteen point sources in the Lake Nockamixon watershed were already subject to 0.5 mg/L total phosphorus discharge limits. Effluent limitations for the remaining three point sources were reduced from 1.0 mg/l to 0.5 mg/l total phosphorus. Point source effluent limitations for total phosphorus used to define baseline conditions are in Appendix F.

Baseline condition loads are used by BATHTUB to predict chlorophyll-a and total phosphorus conditions in Lake Nockamixon. Predicted chlorophyll-a concentrations were compared with the water quality endpoint of 10 ug/L in-lake chlorophyll-a concentration as a seasonal average to determine whether reductions to total phosphorus loads were needed. Total phosphorus loads are reduced until predicted chlorophyll-a values are consistent with the water quality target. Figure 4-2 displays the in-lake total phosphorus and chlorophyll-a concentrations that resulted from using design condition loads for point and nonpoint sources.

As shown in Figure 4-2, using design conditions for total phosphorus loads from point and nonpoint sources results in exccedances of the water quality objective of 10 ug/L. Under these conditions, the chlorophyll-a concentrations ranges from 11 to 14 ug/L while total phosphorus ranges from 30 to 40 ug/L. To achieve seasonal average chlorophyll-a concentrations of 10ug/L or less in Lake Nockamixon, the total phosphorus load delivered to the lake must be reduced. It is important to remember that consistency with water quality targets and standards will be measured in segments 3 and 5. This is based on segmentation of the BATHTUB model to appropriately represent the physical characteristics of Lake Nockamixon.

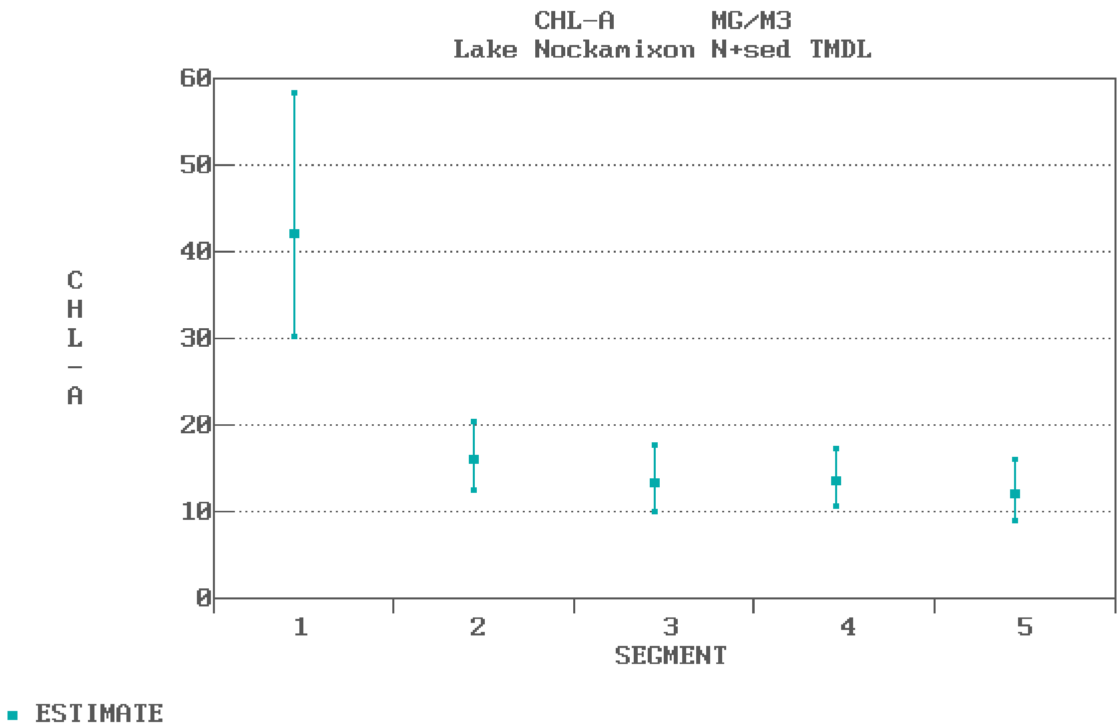


Figure 4-2. Predicted chlorophyll-a concentrations in Lake Nockamixon using design conditions

4.3 TMDL Allocations for Phosphorus

Federal regulations require TMDLs to include load allocations and wasteload allocations, as well as the total allowable load that the waterbody can assimilate while still attaining and maintaining water quality standards. Table 4-2 specifies the load and wasteload allocations, total allowable loads, and margin of safety for the phosphorus and sediment TMDLs for Lake Nockamixon. Pennsylvania DEP did not identify any point sources in the Haycock Creek or direct drainage area subwatersheds in Lake Nockamixon watershed. The Equal Marginal Percent Reduction (EMPR)[1] method is used to allocate total phosphorus loads.

Table 4-2. TMDLs of phosphorus for Lake Nockamixon (lbs/month)

Watershed	LA	WLA*	MOS	TMDL
Tohickon Creek	210.28	530.17	38.97	779.42
Haycock Creek	28.19	0.47	1.51	30.17
Threemile Run	25.95	1.34	1.44	28.73
Direct Drainage Area	23.37	0	1.23	24.6
Lake Nockamixon	**287.79**	**531.98**	**43.15**	**862.92**

*This represents the wasteload allocation given to the entire subwatershed. Individual wasteload allocations are assigned based on NPDES permit limits for total phosphorus and flow.

4.4 Load Allocations of Total Phosphorus

According to federal regulations at 40 CFR Section 130.2(g), load allocations are best estimates of the loading, which may range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading. The AVGWLF process enables the LA to be distributed to sources based on land use type. Table 4-3 below displays the load allocation in Lake Nockamixon by land use.

Table 4-3 Load Allocations of Total Phosphorus for Lake Nockamixon (lb/month)

	Load Allocation				
Land Use	**Tohickon Creek**	**Haycock Creek**	**Threemile Run**	**Direct Drainage Area**	**Lake Nockamixon**
Hay/Pasture	5.48	1.12	0.21	0.34	7.15
Cropland	46.74	7.46	5.87	5.03	65.10
Coniferous Forest	0.05	0.075	0.02	0.04	0.17

[1] Pennsylvania Department of Environmental Protection. June 1986. *Implementation Guidance for the Water Quality Analysis Model* 6.3. Document 391-2000-007.

Load Allocation					
Land Use	**Tohickon Creek**	**Haycock Creek**	**Threemile Run**	**Direct Drainage Area**	**Lake Nockamixon**
Mixed Forest	0.15	0.11	0.04	0.03	0.33
Deciduous Forest	3.24	1.74	1.3	1.42	7.7
Unpaved Roads	0.32	0.33	0.25	0.11	1
Transitional Land	0.14	0.06	0	0	0.2
Low Development	0.13	0.0002	0.002	0	0.13
High Development	1.08	0.002	0.005	0.002	1.09
Streambank	34.57	0.31	0.27	0.75	35.91
Groundwater	109.16	16.08	16.5	14.82	156.57
Septic Systems	9.22	0.9	1.48	0.82	12.44
Total	**210.28**	**28.19**	**25.95**	**23.37**	**287.79**

The EMPR method is executed in the following manner. The total phosphorus load to Lake Nockamixon that ensures compliance with the water quality target of 10 ug/L chlorophyll-a, as determined by AVGWLF and BATHTUB, is used as the target TMDL phosphorus load. The target load is compared with the existing baseline load representing design conditions in the watershed to characterize the total phosphorus reductions needed in the watershed. Design conditions indicate that point sources are discharging total phosphorus at permitted flows and concentrations while nonpoint sources are based on the 6-year average loading conditions as described above.

Once the target TMDL load is established, the total phosphorus sources that will be subject to EMPR must be determined. In Lake Nockamixon, these sources include hay/pasture, cropland, phosphorus loads from streambanks, low and high intensity development, transitional land, and septic systems. Point sources are excluded from EMPR because all point sources in the watershed were subject to total phosphorus effluent limitations of 0.5 mg/l. Groundwater sources are also excluded because of the very limited ability to control phosphorus contributions from groundwater. The remaining sources, which include forested land and unpaved roads, are excluded because the existing loads from these sources are so small in comparison to the total phosphorus load that eliminating the sources outright would not address the problem.

Table 4-4 Percent Reductions Necessary to Meet Load Allocations

Percent reduction					
Land Use	**Tohickon Creek**	**Haycock Creek**	**Threemile Run**	**Direct Drainage area**	**Lake Nockamixon**
Hay/Pasture	46.64	46.64	46.64	46.64	46.64
Cropland	79.57	79.57	79.57	79.57	79.57
Coniferous Forest	0	0	0	0	0
Mixed Forest	0	0	0	0	0
Deciduous Forest	0	0	0	0	0
Unpaved Roads	0	0	0	0	0
Transitional Land	46.64	46.64	46.64	46.64	46.64
Low Development	46.64	46.64	46.64	46.64	46.64
High Development	46.64	46.64	46.64	46.64	46.64
Streambank	46.64	46.64	46.64	46.64	46.64
Groundwater	0	0	0	0	0
Septic Systems	46.64	46.64	46.64	46.64	46.64
Total*	**23.17**	**23.17**	**23.17**	**23.17**	**23.17**

*Total percent reduction does not take into account the Margin of Safety. The percent reduction is 27 percent considering the MOS.

4.5 Wasteload Allocations of Total Phosphorus

EPA regulations require that TMDLs include individual wasteload allocations for all point sources. Pennsylvania DEP identified sixteen point sources in the Lake Nockamixon watershed. Twelve of these point sources are in the Tohickon Creek watershed, three are located in the Threemile Run watershed, and the remaining point source is in the Haycock Creek subwatershed. Table 4-5 summarizes the wasteload allocations for Lake Nockamixon. The wasteload allocation for the direct drainage area are set at zero. Individual wasteload allocations are determined by using the design flow and effluent limitations for total phosphorus. Design flow and effluent limitations were obtained from NPDES permits.

Table 4-5 Individual Wasteload Allocations of Total Phosphorus for Lake Nockamixon

Point Source	NPDES Permit No.	Design Flow (MGD)	Total Phosphorus Concentration (mg/L)	WLA (lb/day)	WLA (lb/month)
Tohickon Creek Subwatershed					
Barryway Ent.	PA0053929	0.0075	0.5	0.0313	0.9383
Bethel Baptist Church	PA0050598	0.0075	0.5	0.0313	0.9383
Freedom Valley Girl Scouts	PA0054364	0.015	0.5	0.0626	1.8765
Giambrone Enterprises	PA0051993	0.008	0.5	0.0334	1.0008
Greentop Mobile Home Park	PA0055395	0.012	0.5	0.05	1.5012
Melody Lakes Mobile Home Park	PA0031178	0.072	0.5	0.3002	9.0072
Peter's Clay Pots	PA0058203	0.002	0.5	0.0083	0.2502
Quakertown WWTP	PA0020290	4	0.5	16.68	500.4
Quakertown Mennonite Church	PA0052787	0.00125	0.5	0.0052	0.1564
Richland Meadows Mobile Home Park	PA0045187	0.08	0.5	0.3336	10.008
Tohickon Family Campground	PA0051586	0.025	0.5	0.1043	3.1275
Tri-County Respite	PA0054704	0.0077	0.5	0.0321	0.9633
			Tohickon Creek subwatershed total	**17.672**	**530.17**
Threemile Run Subwatershed					
Country Place Restaurant	PA0053015	0.00432	0.5	0.018	0.5404
Keelersville Club STP	PA0058548	0.001875	0.5	0.0078	0.2346
Royann Diner	PA0053201	0.0045	0.5	0.0188	0.5630
			Threemile Run subwatershed	**0.0446**	**1.338**
Haycock Creek Subwatershed					

Daniel F. Rufe	PA0058017	0.00382	0.5	0.0159	0.4779
			Haycock Creek Subwatershed	**0.0159**	**0.4779**

4.6 Margin of Safety

The margin of safety is intended to add a level of safety to the modeling process to account for any uncertainty. Margins of safety may be implicit, built into the modeling process, or explicit, taken as a percentage of the wasteload allocation, load allocation, or TMDL

The margin of safety in the Lake Nockamixon watershed is explicit: 5 percent of the total allowable load. This represents 43.15 lb/month of phosphorus. The decision to use 5 percent of the total allowable load is based on best professional judgement and will provide an adequate level of protection to the designated uses of Lake Nockamixon. Pennsylvania DEP believes that the 5 percent margin of safety is justifiable for Lake Nockamixon based on use of the AVGWLF model, which was specifically developed for Pennsylvania. The calibration and validation results, which demonstrate the ability to appropriately recreate observed conditions, also support using the 5 percent margin of safety.

4.7 Reasonable Assurance

EPA requires that there is reasonable assurance that TMDLs can be implemented. In terms of Lake Nockamixon TMDLs of phosphorus, numerous programs exist that can be utilized to help implement TMDLs. For instance, federal regulations at 40 CFR 122.44(d)(1)(vii)(B), require effluent limitations for an NPDES permit to be consistent with the assumptions and requirements of any available WLA for the discharge prepared by the state and approved by EPA. Thus, federal regulations require the wasteload allocations resulting from the development of phosphorus TMDLs for Lake Nockamixon to be implemented.

With regard to load allocations for nonpoint sources, numerous state programs, including Section 319 programs area available. Pennsylvania's Growing Greener funding has provided more than $65 million to environmental initiatives throughout the Commonwealth. Section 319 grant funding, supported by the Unified Watershed Assessment and the Watershed Restoration Action Strategies, is designed to focus resources toward the implementation of Best Management Practices for non-point source pollutants. Pennsylvania has intensified efforts to involve stakeholders early on in the TMDL development process to sustain the interest of the local public until implementation.

TMDLs represent an attempt to quantify the pollutant load that may be present in a waterbody and still ensure attainment and maintenance of water quality standards. The Lake Nockamixon TMDLs identify the necessary overall load reductions for those pollutants currently causing use impairments and distribute those reduction goals to the appropriate nonpoint sources. Reaching the reduction goals established by these TMDLs will only occur through changes in current land use practices, including the incorporation of more agricultural "best management practices" (BMPs). BMPs that would be helpful in lowering the amount of sediment and nutrients reaching Lake Nockamixon include stream bank fencing, riparian buffer strips, strip cropping, contour plowing, conservation crop rotation, and heavy use area protection, among many others.

The Natural Resources Conservation Service maintains a National Handbook of Conservation Practices (NHCP), which provides information on a variety of BMPs. The NHCP is available online at http://www.ftw.nrcs.usda.gov/nhcp_2.html. Many of the practices described in the handbook could be used on agricultural lands in Lake Nockamixon to help limit siltation and nutrient impairments. Determining the most appropriate BMPs, where they should be installed, and actually putting them into practice, will require the development and implementation of a comprehensive watershed restoration plan. Development of any restoration plan will involve the gathering of site-specific information regarding current land uses and existing conservation practices. The required level of detail is outside the scope of this TMDL document and is an activity best accomplished at the local level. Successful implementation of the activities necessary to address current use impairments to Lake Nockamixon will require local citizens taking an active interest in the watershed and the enthusiastic cooperation of local landowners.

By developing TMDLs for the Lake Nockamixon, the Department has set the stage for local citizens to design and implement restoration plans to correct current use impairments. The Department will support local efforts to develop and implement watershed restoration plans based on the reduction goals specified in the TMDLs. Interested parties should contact the appropriate Watershed Manager in the Department's Southeast Regional Office (610-832-6000) for information regarding technical and financial assistance currently available. Individuals and/or local watershed groups interested in "fixing" the identified problems in the Lake Nockamixon are strongly encouraged to avail themselves of funding sources available through DEP and other state and federal agencies (e.g., Growing Greener or 319 Program).

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Appendix A - List of Important Parameters for AVGWLF Model Execution

Areal extent of different land use/cover categories: This parameter is calculated directly from a GIS layer of land use/cover.

Curve number: This parameter determines the amount of precipitation that infiltrates into the ground or enters surface water as runoff. It is based on specified combinations of land use/cover and hydrologic soil type and is calculated directly using digital land use/cover and soils layers.

K factor: This factor relates to inherent soil erodibility, and it affects the amount of soil erosion taking place on a given unit of land.

LS factor: This factor signifies the steepness and length of slopes in an area and directly affects the amount of soil erosion.

C factor: This factor is related to the amount of vegetative cover in an area. In agricultural areas, this factor is largely controlled by the crops grown and the cultivation practices used. Values range from 0 to 1.0, with larger values indicating greater potential for erosion.

P factor: This factor is directly related to the conservation practices used in agricultural areas. Values range from 0 to 1.0, with larger values indicating a greater potential for erosion.

Sediment delivery ratio: This parameter specifies the percentage of eroded sediment delivered to surface water and is empirically based on watershed size.

Unsaturated available water-holding capacity: This parameter relates to the amount of water that can be stored in the soil and affects runoff and infiltration. It is calculated using a digital soils layer.

Dissolved nitrogen in runoff: This parameter varies according to land use/cover type, and reasonable values have been established in the literature. This rate, reported in milligrams per liter, can be readjusted based on local conditions such as rates of fertilizer application and farm animal populations.

Dissolved phosphorus in runoff: Similar to nitrogen, the value for this parameter varies according to land use/cover type, and reasonable values have been established in the literature. This rate, reported in milligrams per liter, can be readjusted based on local conditions such as rates of fertilizer application and farm animal populations.

Nutrient concentrations in runoff over manured areas: These concentrations are user-specified concentrations for nitrogen and phosphorus that are assumed to be representative of surface water runoff leaving areas on which manure has been applied. As with the runoff rates described above, these concentrations are based on values obtained from the literature. They can also be adjusted based on local conditions such as rates of manure application or farm animal populations.

Nutrient buildup in nonurban areas: In GWLF, rates of buildup for both nitrogen and phosphorus have to be specified. In Pennsylvania, these rates are estimated using historical information on atmospheric deposition.

Background nitrogen and phosphorus concentrations in groundwater: Subsurface concentrations of nutrients (primarily nitrogen) contribute to the nutrient loads in streams. In Pennsylvania, these concentrations are estimated using recently published data from the U.S. Geological Survey (USGS).

Background nitrogen and phosphorus concentrations in soil: Because soil erosion results in the transport of nutrient-laden sediment to nearby surface water bodies, reasonable estimates of background concentrations in soil must be provided. In Pennsylvania, this information is based on literature values as well as soil test data collected annually at Penn State University. These values can be adjusted locally depending on manure loading rates and farm animal populations..

Appendix B - Simulated Annual and Monthly Total Phosphorus Loads

Tohickon Creek	April 1996- March 1997 Annual P Load	April 1997 - March 1998 Annual P Load	April 1998 - March 1999 Annual P Load	April 1999 - March 2000 Annual P Load	April 2000 - March 2001 Annual P Load	April 2001 - March 2002 Annual P Load	6-year average Monthly P Load(lb)
Hay/Pasture	152.34	39.93	165.89	164.76	160.67	55.99	10.27
Cropland	3,581.11	1,544.50	3,347.89	3,047.64	3,300.43	1,654.44	228.83
Coniferous Forest	0.39	0.13	0.63	1.23	0.63	0.25	0.05
Mixed Forest	1.36	0.54	2.06	3.89	2.11	0.90	0.15
Deciduous Forest	34.41	18.83	42.58	67.67	44.35	25.31	3.24
Unpaved Roads	4.43	2.65	4.09	4.62	4.21	2.86	0.32
Transitional Lands	3.76	1.99	3.49	4.15	3.49	2.05	0.26
Low Intensity Development	3.17	1.33	2.85	4.51	3.12	2.16	0.24
High Intensity Development	24.92	16.80	25.77	29.79	27.35	20.96	2.02
Streambank	930.26	807.22	773.70	770.27	797.00	586.70	64.79
Groundwater	1,860.72	1,368.75	1,237.59	1,261.38	1,274.89	856.54	109.16
Septic Systems	207.23	207.23	207.23	207.89	207.23	207.23	17.28
Threemile Run	**April 1996 - March 1997 Annual P Load**	**April 1997 - March 1998 Annual P Load**	**April 1998 - March 1999 Annual P Load**	**April 1999 - March 2000 Annual P Load**	**April 2000 - March 2001 Annual P Load**	**April 2001 - March 2002 Annual P Load**	**6-year average Monthly P Load(lb)**
Hay/Pasture	4.11	0.64	6.70	8.40	6.88	2.01	0.40
Cropland	407.60	183.34	414.74	416.92	419.07	225.72	28.71
Coniferous Forest	0.15	0.07	0.22	0.39	0.22	0.11	0.02
Mixed Forest	0.44	0.21	0.60	1.05	0.62	0.31	0.04
Deciduous Forest	15.41	9.79	16.51	22.12	17.48	12.00	1.30
Unpaved Roads	3.47	2.13	3.20	3.56	3.32	2.33	0.25
Transitional Lands	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Low Intensity Development	0.05	0.02	0.04	0.07	0.05	0.03	0.00
High Intensity Development	0.13	0.07	0.13	0.16	0.13	0.10	0.01
Streambank	7.22	6.33	5.99	6.02	6.24	4.62	0.51
Groundwater	280.90	204.36	189.20	191.41	193.41	129.07	16.50
Septic Systems	33.29	33.29	33.29	33.51	33.29	33.29	2.78

Haycock Creek	April 1996 - March 1997 Annual P Load	April 1997 - March 1998 Annual P Load	April 1998 - March 1999 Annual P Load	April 1999 - March 2000 Annual P Load	April 2000 - March 2001 Annual P Load	April 2001 - March 2002 Annual P Load	6-year average Monthly P Load(lb)
Hay/Pasture	30.95	8.75	33.47	33.28	32.56	12.00	2.10
Cropland	559.84	261.62	522.03	482.67	520.81	283.83	36.54
Coniferous Forest	0.93	0.35	1.04	1.56	1.02	0.44	0.07
Mixed Forest	1.35	0.56	1.48	2.16	1.46	0.68	0.11
Deciduous Forest	20.79	13.25	22.18	29.57	23.51	16.21	1.74
Unpaved Roads	4.47	2.85	4.12	4.50	4.31	3.15	0.32
Transitional Lands	1.62	0.95	1.44	1.59	1.47	0.94	0.11
Low Intensity Development	0.00	0.00	0.00	0.01	0.00	0.00	0.00
High Intensity Development	0.05	0.03	0.05	0.06	0.06	0.04	0.00
Streambank	8.34	7.30	6.96	6.96	7.18	5.32	0.58
Groundwater	273.85	199.80	184.27	186.50	187.61	125.69	16.08
Septic Systems	20.28	20.28	20.28	20.50	20.28	20.28	1.69

Direct Drainage	April 1996 - March 1997 Annual P Load	April 1997 - March 1998 Annual P Load	April 1998 - March 1999 Annual P Load	April 1999 - March 2000 Annual P Load	April 2000 - March 2001 Annual P Load	April 2001 - March 2002 Annual P Load	6-year average Monthly P Load(lb)
Hay/Pasture	9.49	2.47	10.34	10.27	10.01	3.47	0.64
Cropland	385.41	166.12	360.32	327.97	355.18	177.93	24.62
Coniferous Forest	0.34	0.13	0.51	0.97	0.52	0.22	0.04
Mixed Forest	0.29	0.11	0.44	0.83	0.45	0.19	0.03
Deciduous Forest	16.46	10.13	18.25	25.61	19.25	12.66	1.42
Unpaved Roads	1.50	0.90	1.38	1.56	1.42	0.97	0.11
Transitional Lands	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Low Intensity Development	0.00	0.00	0.00	0.00	0.00	0.00	0.00
High Intensity Development	0.04	0.02	0.04	0.05	0.04	0.03	0.00
Streambank	20.23	17.56	16.69	16.89	17.35	12.84	1.41
Groundwater	255.07	182.16	169.92	173.27	172.66	114.27	14.82
Septic Systems	18.52	18.52	18.52	18.52	18.52	18.52	1.54

Lake Nockamixon	April 1996 - March 1997 Annual P Load	April 1997 - March 1998 Annual P Load	April 1998 - March 1999 Annual P Load	April 1999 - March 2000 Annual P Load	April 2000 - March 2001 Annual P Load	April 2001 - March 2002 Annual P Load	6-year average Monthly P Load(lb)

Hay/Pasture	196.89	51.79	216.40	216.71	210.12	73.47	13.41
Cropland	4,933.96	2,155.58	4,644.96	4,275.19	4,595.48	2,341.92	318.71
Coniferous Forest	1.81	0.69	2.40	4.15	2.39	1.01	0.17
Mixed Forest	3.43	1.42	4.59	7.92	4.63	2.08	0.33
Deciduous Forest	87.08	51.99	99.52	144.97	104.60	66.18	7.70
Unpaved Roads	13.87	8.53	12.79	14.25	13.26	9.30	1.00
Transitional Lands	5.38	2.94	4.93	5.73	4.96	3.00	0.37
Low Intensity Development	3.22	1.36	2.89	4.58	3.17	2.20	0.24
High Intensity Development	25.14	16.94	25.99	30.05	27.59	21.14	2.04
Streambank	966.04	838.41	803.33	800.14	827.78	609.48	67.29
Groundwater	2,670.54	1,955.07	1,780.99	1,812.56	1,828.58	1,225.56	156.57
Septic Systems	279.32	279.32	279.32	280.43	279.32	279.32	23.29

Appendix C - Monthly Point Source Phosphorus Loads in the Tohickon Creek Watershed

Facility	Barryway Enterprises	Bethel Baptist	Greentop MHP	Melody Lakes MHP	Quakertown WWTP*	Quakertown United Mennonite	Richland Meadows MHP	Clover D/Tohickon Campground	Tri-County Respite	Total P Load (lb/month)
NPDES #	PA0053929	PA0050598	PA000055395	PA0031178	PA0020290	PA0052787	PA0045187	PA0051586	PA0054704	
Month										
January-97	0.64	0.41	4.06	6.78	170.33	0.12	6.58	0.19	0.27	189.38
February-97	0.58	0.37	2.82	4.14	154.02	0.05	4.99	0.13	0.25	167.34
March-97	0.64	0.43	1.14	15.00	170.33	0.11	13.23	0.05	0.25	201.18
April-97	0.47	0.34	0.50	7.38	164.89	0.06	13.42	0.18	0.27	187.50
May-97	0.49	0.34	0.53	7.76	170.33	0.01	52.57	0.10	0.26	232.39
June-97	0.60	0.26	0.73	6.56	155.26	0.05	27.93	0.76	0.33	192.49
July-97	0.75	0.29	0.70	8.85	140.15	0.04	8.06	0.16	0.63	159.62
August-97	1.54	0.29	1.57	5.90	197.50	0.03	15.70	0.18	0.24	222.93
September-97	0.57	0.33	3.81	6.56	191.34	0.06	15.03	0.20	0.27	218.17
October-97	0.48	0.37	0.79	4.35	154.80	0.04	3.35	0.29	0.29	164.76
November-97	0.55	0.63	0.47	4.21	151.57	0.03	5.47	0.14	0.25	163.31
December-97	0.39	0.86	0.84	2.90	180.29	0.05	5.27	0.17	0.09	190.84
January-98	0.63	0.86	0.40	5.55	222.10	0.06	6.68	0.16	0.17	236.61
February-98	0.51	0.67	0.29	2.71	211.08	0.04	5.40	0.06	0.11	220.88
March-98	0.74	1.30	0.36	4.58	236.68	0.01	7.44	0.19	0.17	251.46
April-98	0.61	1.23	0.55	5.81	207.47	0.06	6.35	0.52	0.11	222.71
May-98	0.51	0.74	0.69	9.00	345.92	0.07	14.63	0.56	0.15	372.28
June-98	0.56	0.50	0.82	7.26	226.94	0.18	16.34	0.45	0.19	253.23
July-98	0.89	0.65	0.45	15.22	201.11	0.12	5.47	0.25	0.18	224.34
August-98	0.89	0.53	0.91	18.00	186.22	0.07	3.20	0.21	0.21	210.24
September-98	0.69	0.12	0.70	4.99	194.21	0.01	3.04	0.10	0.16	204.03
October-98	0.41	0.27	0.20	7.86	212.67	0.01	3.26	0.17	0.05	224.91
November-98	0.49	0.57	0.50	4.36	127.81	0.01	6.55	0.24	0.38	140.91
December-98	0.42	1.04	0.44	7.86	114.63	0.14	4.69	0.12	0.17	129.52
January-99	0.56	0.30	0.18	3.10	211.66	0.01	6.20	0.08	0.19	222.28
February-99	0.41	0.19	0.46	6.37	145.77	0.01	4.89	0.07	0.19	158.36
March-99	0.38	0.20	0.52	4.58	180.63	0.02	4.11	0.10	0.19	190.72
April-99	0.53	0.15	0.49	7.38	169.31	0.01	1.69	0.20	0.18	179.94
May-99	0.51	0.26	1.19	7.37	195.93	0.01	4.83	0.52	0.12	210.73

Facility	Barryway Enterprises	Bethel Baptist	Greentop MHP	Melody Lakes MHP	Quakertown WWTP*	Quakertown United Mennonite	Richland Meadows MHP	Clover D/Tohickon Campground	Tri-County Respite	Total P Load (lb/month)
NPDES #	PA0053929	PA0050598	PA000055395	PA0031178	PA0020290	PA0052787	PA0045187	PA0051586	PA0054704	
June-99	0.45	0.42	0.38	22.43	167.55	0.01	6.83	0.30	0.32	198.69
July-99	0.46	0.08	0.60	4.04	167.55	0.02	5.60	0.39	0.28	179.02
August-99	0.46	0.11	0.64	0.76	189.40	0.01	6.05	0.72	0.24	198.40
September-99	0.45	0.13	0.87	7.26	238.53	0.01	5.02	0.38	0.18	252.83
October-99	0.46	0.17	0.60	0.65	205.74	0.01	5.48	0.31	0.38	213.80
November-99	0.45	0.28	0.66	10.21	230.41	0.01	5.50	0.60	0.16	248.28
December-99	0.31	0.19	0.53	8.69	262.39	0.01	4.58	0.26	0.11	277.08
January-00	0.24	0.45	0.73	0.61	168.73	0.02	6.89	0.10	0.18	177.95
February-00	0.48	0.90	3.87	0.64	240.96	0.00	10.17	0.29	0.11	257.42
March-00	0.43	0.69	1.13	1.50	322.73	0.02	8.80	0.31	0.14	335.75
April-00	0.29	0.31	1.23	5.41	199.64	0.02	4.16	0.31	0.29	211.64
May-00	0.35	1.09	0.74	10.40	246.39	0.02	4.19	0.32	0.14	263.64
June-00	0.37	1.38	1.08	9.99	195.30	0.02	8.41	0.31	0.19	217.05
July-00	0.34	0.08	1.51	5.79	189.84	0.03	6.58	0.26	0.21	204.64
August-00	0.35	0.12	0.84	7.24	231.87	0.02	4.87	0.39	0.20	245.90
September-00	0.40	0.22	0.92	13.77	174.96	0.02	3.44	0.40	0.20	194.32
October-00	0.21	0.14	0.94	3.00	186.27	0.02	4.49	0.78	0.36	196.20
November-00	0.14	0.18	0.87	7.01	161.76	0.01	0.95	0.15	0.17	171.24
December-00	0.30	0.52	0.73	7.24	168.06	0.02	2.75	0.16	0.25	180.04
January-01	0.24	0.37	0.59	5.90	165.04	0.01	7.14	0.18	0.30	179.76
February-01	0.05	0.22	0.59	4.70	192.83	0.06	2.84	0.05	0.27	201.61
March-01	0.07	0.80	1.11	8.28	203.38	0.02	3.85	0.10	0.36	217.98
April-01	0.05	0.30	1.37	4.36	201.67	0.02	1.80	0.13	0.25	209.94
May-01	0.15	0.08	1.14	13.50	268.20	0.59	5.35	0.18	0.15	289.35
June-01	0.11	1.16	0.79	4.21	215.27	0.06	9.91	0.38	0.21	232.11
July-01	0.07	0.03	0.95	3.72	247.06	0.02	6.42	0.26	0.29	258.82
August-01	0.33	0.01	1.03	11.65	204.94	0.02	4.69	0.39	0.43	223.50
September-01	0.44	0.07	0.91	8.71	165.22	0.01	2.65	0.15	0.19	178.35
October-01	0.29	0.08	0.75	7.37	146.78	0.11	2.11	0.21	0.21	157.91
November-01	0.18	0.06	0.92	7.01	140.32	0.02	12.52	0.15	0.16	161.33
December-01	0.30	0.17	1.05	3.83	138.77	0.02	4.27	0.05	0.16	148.63

Facility	Barryway Enterprises	Bethel Baptist	Greentop MHP	Melody Lakes MHP	Quakertown WWTP*	Quakertown United Mennonite	Richland Meadows MHP	Clover D/Tohickon Campground	Tri-County Respite	Total P Load (lb/month)
NPDES #	PA0053929	PA0050598	PA000055395	PA0031178	PA0020290	PA0052787	PA0045187	PA0051586	PA0054704	
January-02	0.36	0.07	0.74	4.27	177.10	0.10	3.75	0.10	0.14	186.65
February-02	0.44	0.07	0.50	10.28	142.14	0.09	3.60	0.05	0.13	157.29
March-02	0.54	0.08	0.63	5.79	203.11	0.10	2.52	0.11	0.14	213.04

Appendix D - Monthly Point Source Phosphorus Loads in Threemile Run Watershed

Facility	Royann Diner	Country Place	Total P Load
NPDES #	PA0053201	PA0053015	(lb/month)
Month			
January-97	2.11	0.06	2.17
February-97	0.32	0.07	0.39
March-97	0.29	0.06	0.35
April-97	0.19	0.04	0.23
May-97	0.10	0.07	0.17
June-97	1.70	0.11	1.81
July-97	0.62	0.16	0.77
August-97	0.19	0.21	0.40
September-97	0.23	0.07	0.30
October-97	0.21	0.06	0.27
November-97	6.81	0.04	6.85
December-97	4.40	0.14	4.54
January-98	0.84	0.10	0.94
February-98	1.02	0.07	1.09
March-98	0.18	0.07	0.25
April-98	2.50	0.07	2.57
May-98	2.59	0.25	2.84
June-98	0.35	0.19	0.54
July-98	0.16	0.57	0.73
August-98	0.14	0.18	0.32
September-98	1.18	0.32	1.50
October-98	0.20	0.11	0.31
November-98	0.19	0.07	0.26
December-98	0.23	0.10	0.33
January-99	0.93	0.07	1.00
February-99	0.14	0.05	0.19
March-99	0.34	0.08	0.42
April-99	0.48	0.13	0.61
May-99	0.69	0.14	0.83
June-99	0.19	0.19	0.38
July-99	0.27	0.17	0.45
August-99	0.20	0.20	0.40
September-99	0.16	0.16	0.32
October-99	0.10	0.24	0.35
November-99	0.10	0.16	0.25
December-99	0.16	0.05	0.21
January-00	0.09	0.19	0.28
February-00	0.09	0.09	0.18
March-00	0.06	0.18	0.24

Facility	Royann Diner	Country Place	Total P Load
NPDES #	PA0053201	PA0053015	(lb/month)
April-00	0.15	0.34	0.49
May-00	0.04	0.17	0.22
June-00	0.16	0.50	0.66
July-00	0.32	0.25	0.56
August-00	0.30	0.16	0.47
September-00	0.05	0.06	0.12
October-00	0.20	0.10	0.30
November-00	0.04	0.05	0.09
December-00	0.27	0.15	0.42
January-01	0.15	0.09	0.24
February-01	0.05	0.16	0.21
March-01	0.17	0.18	0.35
April-01	0.05	0.27	0.32
May-01	0.05	0.23	0.28
June-01	0.06	0.25	0.31
July-01	0.10	0.23	0.33
August-01	0.21	0.15	0.36
September-01	0.22	0.18	0.40
October-01	0.56	0.10	0.65
November-01	0.12	0.17	0.29
December-01	0.07	0.16	0.23
January-02	0.10	0.13	0.22
February-02	0.35	0.16	0.51
March-02	0.28	0.13	0.41

Appendix E. Simulated Annual Sediment Loads

Subwatershed/Source	Annual Sediment Loads (lb)						
	April 1996 - March 1997	April 1997 - March 1998	April 1998 - March 1999	April 1999 - March 2000	April 2000 - March 2001	April 2001 - March 2002	6-year Average
Tohickon Creek							
Hay/Pasture	3,089.61	2,216.35	2,828.91	2,901.96	3,059.46	2,530.67	2,771.16
Cropland	3,966,945.79	2,845,334.04	3,632,151.64	3,725,882.35	3,928,281.01	3,249,597.14	3,558,031.99
Coniferous Forest	47.64	34.35	43.75	44.72	47.32	39.21	42.83
Mixed Forest	585.01	418.98	535.20	548.87	579.15	478.55	524.29
Deciduous Forest	277,455.06	199,002.98	254,035.94	260,589.06	274,754.38	227,280.68	248,853.02
Unpaved Roads	14.58	10.46	13.35	13.70	14.44	11.94	13.08
Transitional Lands	10.70	7.67	9.80	10.04	10.59	8.77	9.59
Low Intensity Development	3,067.96	2,786.05	2,840.23	1,921.71	3,045.10	2,780.97	2,740.34
High Intensity Development	1,304.68	1,031.96	931.01	656.19	1,053.00	1,020.05	999.48
Streambank	3,298.80	2,862.50	2,743.60	2,731.44	2,826.26	2,080.48	2,757.18
Total	4,255,819.82	3,053,705.34	3,896,133.42	3,995,300.04	4,213,670.69	3,485,828.47	3,816,742.96
Threemile Run							
Hay/Pasture	32.92	23.63	30.12	30.89	32.56	26.96	29.51
Cropland	159,411.31	114,339.28	145,957.46	149,723.73	157,858.01	130,584.64	142,979.07
Coniferous Forest	7.50	5.37	6.85	7.04	7.41	6.11	6.71
Mixed Forest	58.33	41.91	53.57	54.76	57.86	47.86	52.38
Deciduous Forest	33,262.90	23,856.92	30,455.70	31,242.63	32,939.54	27,247.88	29,834.26
Unpaved Roads	8.81	6.32	8.07	8.28	8.73	7.22	7.90
Transitional Lands	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Low Intensity Development	46.26	42.00	42.85	29.01	45.98	42.00	41.35
High Intensity Development	9.26	7.87	7.45	5.28	8.24	7.87	7.66
Streambank	27.18	23.82	22.57	22.66	23.51	17.41	22.86
Total	192,864.47	138,347.11	176,584.64	181,124.28	190,981.83	157,987.94	172,981.71
Haycock Creek							
Hay/Pasture	287.20	205.90	262.87	269.77	284.34	235.17	257.54
Cropland	140,270.41	100,609.85	128,432.06	131,746.19	138,902.48	114,905.36	125,811.06
Coniferous Forest	46.71	33.61	42.78	43.87	46.27	38.19	41.91

Subwatershed/Source	Annual Sediment Loads (lb)						
	April 1996 - March 1997	April 1997 - March 1998	April 1998 - March 1999	April 1999 - March 2000	April 2000 - March 2001	April 2001 - March 2002	6-year Average
Mixed Forest	113.47	81.34	104.09	106.65	112.34	93.00	101.81
Deciduous Forest	61,156.61	43,864.47	55,997.19	57,442.28	60,562.02	50,100.18	54,853.79
Unpaved Roads	13.00	9.33	11.90	12.21	12.87	10.65	11.66
Transitional Lands	1.38	0.99	1.27	1.30	1.37	1.13	1.24
Low Intensity Development	4.86	4.42	4.50	3.06	4.84	4.40	4.35
High Intensity Development	2.59	2.06	1.85	1.30	2.09	2.04	1.99
Streambank	32.44	28.41	27.07	27.10	27.95	20.71	27.28
Total	201,928.68	144,840.39	184,885.59	189,653.72	199,956.57	165,410.83	181,112.63
Direct Drainage							
Hay/Pasture	13.11	9.38	11.98	12.31	12.99	10.72	11.75
Cropland	54,177.58	38,859.70	49,605.23	50,885.46	53,649.94	44,380.44	48,593.06
Coniferous Forest	41.85	30.10	38.17	39.40	41.36	34.26	37.52
Mixed Forest	30.79	22.20	28.27	29.11	30.58	25.34	27.72
Deciduous Forest	50,830.97	36,460.41	46,539.94	47,740.97	50,333.07	41,637.00	45,590.39
Unpaved Roads	1.96	1.40	1.79	1.84	1.94	1.60	1.75
Transitional Lands	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Low Intensity Development	0.36	0.33	0.33	0.23	0.35	0.33	0.32
High Intensity Development	3.02	2.56	2.44	1.73	2.69	2.56	2.50
Streambank	84.82	73.63	69.97	70.82	72.74	53.83	70.97
Total	105,184.46	75,459.72	96,298.14	98,781.88	104,145.65	86,146.09	94,335.99
Lake Nockamixon							
Hay/Pasture	3,422.84	2,455.26	3,133.88	3,214.94	3,389.34	2,803.53	3,069.96
Cropland	4,320,805.08	3,099,142.87	3,956,146.39	4,058,237.73	4,278,691.43	3,539,467.59	3,875,415.18
Coniferous Forest	143.69	103.43	131.56	135.03	142.35	117.78	128.97
Mixed Forest	787.60	564.42	721.13	739.39	779.92	644.75	706.20
Deciduous Forest	422,705.54	303,184.77	387,028.77	397,014.94	418,589.01	346,265.73	379,131.46
Unpaved Roads	38.36	27.51	35.12	36.02	37.97	31.42	34.40
Transitional Lands	12.08	8.66	11.06	11.34	11.96	9.90	10.84
Low Intensity Development	3,119.44	2,832.80	2,887.91	1,954.00	3,096.27	2,827.70	2,786.36
High Intensity Development	1,319.55	1,044.46	942.76	664.50	1,066.01	1,032.52	1,011.63

Subwatershed/Source	Annual Sediment Loads (lb)						
	April 1996 - March 1997	April 1997 - March 1998	April 1998 - March 1999	April 1999 - March 2000	April 2000 - March 2001	April 2001 - March 2002	6-year Average
Streambank	3,443.24	2,988.37	2,863.21	2,852.02	2,950.46	2,172.43	2,878.29
Total	4,755,797.43	3,412,352.56	4,353,901.79	4,464,859.91	4,708,754.73	3,895,373.33	4,265,173.29

Appendix F. Baseline Condition Point Source Effluent Limitations

Subwatershed / Source	NPDES Permit Number	Design Flow (mgd)	Total Phosphorus Concentration (mg/l)
Tohickon Creek			
Barryway Enterprise	PA0053929	0.0075	0.5
Bethel Baptist Church	PA0050598	0.0075	0.5
Freedom Valley Girl Scouts	PA0054364	0.015	0.5
Giambrone Enterprises	PA0051993	0.008	0.5
Greentop Mobile Home Park	PA0055395	0.012	0.5
Melody Lakes Mobile Home Park	PA0031178	0.072	0.5
Peter’s Clay Pots	PA0058203	0.002	1
Quakertown WWTP	PA0020290	4	0.5
Quakertown Mennonite Church	PA0052787	0.00125	0.5
Richland Meadows Mobile Home Park	PA0045187	0.08	0.5
Tohikon Family Campground	PA0051586	0.025	0.5
Tri-County Respite	PA0054704	0.0077	0.5
Threemile Run			
Country Place Restaurant	PA0053015	0.00432	0.5
Kellersville Club STP	PA0058548	0.001875	1
Royann Diner	PA0053201	0.0045	0.5
Haycock Creek			
Daniel F. Rufe	PA0058017	0.00382	1

Appendix G: Comment and Response Document

Lake Nockamixon TMDL

Comments received from:

(1) Michael J. Noone
(2) Jim N.
(3) Gretchen Schatschneider
(4) Leonard Crooke

Comment 5: The "Target" level of nutrients that is desired for the Lake must be **less than** the TMDL calculation (which, by definition, is a "Maximum"). The DEP should, therefore, be recommending policies and practices that will assure that the levels of the limiting nutrient, phosphorus, be **less than** the calculated "Maximum" daily load. Unless this is the case, the quality of the water in the Lake will, by definition, not improve in the future. The "Target" chlorophyll-a concentration should be adjusted accordingly. (1)

Response 5: : Do not assume that the water quality will not improve by allowing the total maximum daily load of phosphorus that is consistent with the water quality target. This argument presumes that the target itself is not protective of water quality.

The water quality target for Lake Nockamixon is to achieve an in-lake seasonal chlorophyll-a average of 10 micrograms per liter. This level of chlorophyll-a in the lake was chosen because it is consistent with water quality standards and protective of designated uses for Lake Nockamixon. Furthermore, water quality analysis, using watershed and water quality modeling, determined the allowable phosphorus load to Lake Nockamixon that would ensure consistency with the water quality target. The TMDL of phosphorus for Lake Nockamixon requires source reductions of almost 23% and is designed to improve the trophic status of the lake, decrease algal production and the likelihood of algal blooms, increase clarity, and help prevent aquatic life impacts from low dissolved oxygen.

Moreover, the margin of safety reserves a percentage of the TMDL to account for uncertainty in the TMDL process. The remaining allowable load is allocated to sources of phosphorus. Therefore, as a matter of process, the allowable load of phosphorus IS less than the TMDL by a magnitude equal to the margin of safety.

Comment 6: The construction of "high-end" homes in the area of Three Mile Run has dramatically changed the amount of run-off of both nutrients and silt. (2)

Response 6: The TMDL proposes reduced loads from 'transitional lands' that include land disturbance from new development. We will be working with the County Conservation District to require Best Management Practices for construction, that would addresses the necessary reductions.

Comment 7: Last weekend I drove around the Tohickon watershed area to see what was out there. I also talked to some people I know that either live near that area or are familiar with it. I found several probable problem areas such as farmland and old septic systems. One area of particular interest is a place called Schabels (Kelly Farms) located at 906 W. Thatcher Rd. in Haycock. I was told that there are about 100 cabins back there much of which are used only in the summer but some may permanent residents. After seeing this I came up with several questions.
(1) Do these cabins/houses have any kind of septic system and if so what kind?
(2) Has this area been checked to see if there is a problem here?
(3) If this is a problem area is there anything that can be done about it? (2)

Response 7: The TMDL includes estimated loads from septic systems. In response to some information obtained at the public meeting, the DEP contacted the Bucks County Health Department and requested information pertaining to this location. There are between 100-200 cabins, generally with cesspools. There were repairs and upgrades made at this location, as conditions/complaints warranted, however the Health Department does not have any current complaints regarding malfunctioning systems at this location.

Comment 8: The DEP should obtain more recent land use percentages. (3)

Response 8: Development of the TMDL was performed using the latest available data on land uses in the area. As more recent data becomes, the TMDL can be revised or updated to reflect changes in land uses.

Comment 9:Now that one of the NPDES point sources in closed, how will that affect the reduction of Phosphorus? (3)

Response 9: The phosphorus load attributed to that point source can be redistributed in other allocations.

Comment 10: Do you believe that an 83% reduction in NPS pollution from agriculture is attainable? (3)

Response 10: That figure from the Draft TMDL is revised in the final TMDL.

Comment 11: Why are computer models being used instead of actual lake/watershed assessments? I would prefer more site-specific data. (3)

Response 11: The TMDL of phosphorus for Lake Nockamixon uses site-specific data. Please refer to Section 2 of the TMDL report.

Watershed and water quality models are used to provide a more comprehensive approach to water quality studies and TMDL development. Among other things, computer models allow easier and more rapid incorporation and analysis of data, enhanced analytical and assessment abilities, as well as generation and visualization of model results.

Furthermore, computer models can facilitate the analysis of management measures for implementation and monitoring of TMDLs.

Comment 12: Please review the Lake Nockamixon 2001 Water Quality Report and revise your data. (3)

Response 12**:** The Water Quality Summary Report, July 2001, performed by FX Browne, Inc. was considered during the analysis.

Comment 13: New aerial photographs of this watershed will be available in June 2003. Possibly this could help with land use. (3)

Response 13: It may help us to revise the TMDL in the future.

Comment 14: In January of 1982 the Bucks County Conservation District commissioned a study to FX Browne Associates, INC. This "Lake Nockamixon Phase I Diagnostic-Feasibility Study" was funded by the Commonwealth of Pennsylvania Department of Environmental Resources Clean Water Fund. The report tendered in June of 1983 indicated that the lake was severely hypereutrophic. The sources of pollutants were demonstrated to be about 50% from Quakertown Waste Water Treatment Plant, 28% from cropland, and 7% from failing on lot septic systems failures. Quakertown Waste Water Treatment Plant subsequently spent 11 million dollars to up grade to tertiary treatment of their waste water. Thirty farmers and landowners using an EPA Grant of $239,700 for a three year water shed management implementation program augmented by cost share funds paid for by the farmers themselves put BMPs on the cropland in the watershed. The Bucks County Board of Health had no solution for the failing septic systems. I believe we should have taken issue with their response. From the September 1993 EPA Clean Lakes Program Phase II Final Report- Lake Nockamixon water quality has improved primarily due to implementation of agricultural BMPs put on the watershed cropland, the new Tertiary Treatment at the Quakertown Plant and public education programs geared towards farmers and land use practices. (4)

Response 14: With regard to the efforts of the Bucks County Health Department (BCHD) with failing septic systems, their program to address failing septic systems consists of two major components. First, they respond to complaints of failing septic systems, and require repairs/upgrades where necessary. Second, where a system fails certification, for example, as required by a mortgage company for a property transfer, the BCHD requires the repair or replacement of the septic system. While the specific number isn't available for the Nockamixon watershed, BCHD logged over 200 repairs or replacements of failing septic systems in 2002.
Lake water quality has improved steadily since 1986. The Carlson TSI's for P, chlorophyll-a and Secchi disc respectively are as follows: 1986 – 64, 52, 52; 1988 – 60, 56, 53; 1995 – 57, 54, 52; 1999 – 60, 46, 46; 2000 – 48, 55, 50; 2001 – 47, 60 53; 2002 – 45, 20*, 46. These trends indicates that the lake is nearly mesotrophic.

*This TSI of 20 corresponds to a chlorophyll-a concentration of zero. The only other case where we got a chlorophyll-a concentration of zero was a lake sample two weeks after it had been treated with an herbicide. Lake Nockamixon had been treated on 7/12/2002 (The DEP WQNL survey was on 9/9/02). Fifteen acres were treated. The treatments were located near boat docks and launch ramps. The DEP survey station was located near the dam at the deepest part of the lake, and the chlorophyll-a at that location was most likely not affected by the herbicide treatment. There was no indication of lab error.