

Total Maximum Daily Load (TMDL) Assessment for the Neshaminy
Creek Watershed in Southeast Pennsylvania

(Revised December 2003)

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A1.0 OVERVIEW

This comprehensive document has been prepared to address all of the impaired stream segments contained within the Neshaminy Creek watershed located in Bucks and Montgomery Counties, Pennsylvania (see Figure A1). This urbanized watershed, which comprises about 148,679 acres (or about 232 square miles), is located primarily in the Piedmont physiographic province to the north of Philadelphia. In terms of land use/cover, it is approximately 24% developed, 38% agriculture, 36% wooded, and 2% other (primarily wetland and disturbed), and has approximately 418.3 miles of streams. Since 1996, 203.3 miles of these streams (about 48.6%) have been included on Pennsylvania's 303(d) list of streams having aquatic life use impairments. A complete listing of the segments impacted, along with their respective sources and causes of impairment, is given in Table A1.

The Neshaminy Creek watershed as a whole is very much a point source-dominated system. On an annual basis, the municipal wastewater treatment plants in the watershed contribute about 25% of the total phosphorus load. During critical low-flow periods, effluent discharges comprise over 90% of the total stream flow in many reaches. Upland erosion from developing areas and agriculture, and streambank erosion are other major sources of phosphorus, as well as sediment.

Within this document, the different sections have been organized to address impairments by geographic unit (i.e., sub-watershed) and by source and cause of impairment. Section B provides an overview of the hydrologic/water quality modeling approaches used to assess loads for various sub-areas and stream reaches within the Neshaminy Creek watershed. Section C describes the results for nonpoint source-related assessments. Section D describes the results for assessments involving stream segments previously determined to be impaired by municipal point source discharges.



Figure A1. Location of Neshaminy Creek watershed.

Table A1.

Aquatic Life Use
303(d) List of Streams and Sources of Impairments

Data Source	Source	Cause	Priority	Year Listed	Targeted for TMDL
State Water Plan:02F					
Named Streams: 02F - Cooks Run					
Segment ID: 482 Miles Assessed: 1.4					
Surface Water Monitoring Program	Urban Runoff/Storm Sewers	Cause Unknown	Low	1996	
Surface Water Monitoring Program	Urban Runoff/Storm Sewers	Nutrients	Medium	1996	
Segment ID: 482A Miles Assessed: 3.2					
Surface Water Monitoring Program	Municipal Point Source	Nutrients	Medium	1996	2003
Surface Water Monitoring Program	Urban Runoff/Storm Sewers	Cause Unknown	Low	1996	2003
Surface Water Monitoring Program	Urban Runoff/Storm Sewers	Nutrients	Medium	1996	2003
Named Streams: 02F - Core Creek					
Segment ID: 980602-0954-GLW Miles Assessed: 15.8					
Surface Water Assessment Program	Agriculture	Siltation	Medium	2002	
Named Streams: 02F - Little Neshaminy Creek					
Segment ID: 980616-1108-GLW Miles Assessed: 5.5					
Surface Water Assessment Program	Urban Runoff/Storm Sewers	Water/Flow Variability	Low	1998	
Surface Water Assessment Program	Urban Runoff/Storm Sewers	Siltation	Medium	1998	
Segment ID: 980616-1316-GLW Miles Assessed: 6.2					
Surface Water Assessment Program	Urban Runoff/Storm Sewers	Water/Flow Variability	Low	2002	
Surface Water Assessment Program	Urban Runoff/Storm Sewers	Siltation	Medium	2002	
Segment ID: 980629-1341-GLW Miles Assessed: 10.5					
Surface Water Assessment Program	Urban Runoff/Storm Sewers	Water/Flow Variability	Low	2002	
Surface Water Assessment Program	Urban Runoff/Storm Sewers	Siltation	Medium	2002	
Segment ID: 980629-1342-GLW Miles Assessed: 15.7					
Surface Water Assessment Program	Urban Runoff/Storm Sewers	Water/Flow Variability	Low	2002	2003
Surface Water Assessment Program	Municipal Point Source	Nutrients	Medium	1996	2003
Surface Water Assessment Program	Urban Runoff/Storm Sewers	Siltation	Medium	2002	2003
Named Streams: 02F - Mill Creek					
Segment ID: 20000525-1017-GLW Miles Assessed: 0.8					
Surface Water Assessment Program	Surface Mining	Siltation	Medium	2002	
Surface Water Assessment Program	Surface Mining	Flow Alterations	Low	2002	
Segment ID: 20010417-1342-GLW Miles Assessed: 1.8					
Surface Water Assessment Program	Municipal Point Source	Nutrients	Medium	2002	
Segment ID: 20010426-1512-GLW Miles Assessed: 2.2					
Surface Water Assessment Program	Urban Runoff/Storm Sewers	Siltation	Medium	2002	
Segment ID: 980609-1425-GLW Miles Assessed: 3.9					
Surface Water Assessment Program	Small Residential Runoff	Flow Alterations	Low	2002	
Surface Water Assessment Program	Small Residential Runoff	Siltation	Medium	2002	
Named Streams: 02F - Park Creek					
Segment ID: 20010510-1303-GLW Miles Assessed: 0.2					
Surface Water Assessment Program	Other	Oil and Grease	Medium	2002	
Segment ID: 20010511-1045-GLW Miles Assessed: 1.7					
Surface Water Assessment Program	Urban Runoff/Storm Sewers	Siltation	Medium	2002	
Segment ID: 980622-1146-GLW Miles Assessed: 6.2					
Surface Water Assessment Program	Municipal Point Source	Nutrients	Medium	2002	2003
Surface Water Assessment Program	Municipal Point Source	DO/BOD	Medium	1996	2003
Surface Water Assessment Program	Urban Runoff/Storm Sewers	Siltation	Medium	2002	2003
Surface Water Assessment Program	Urban Runoff/Storm Sewers	Water/Flow Variability	Low	2002	2003
Segment ID: 980622-1147-GLW Miles Assessed: 1.2					
Surface Water Assessment Program	Municipal Point Source	Nutrients	Medium	2002	2003
Surface Water Assessment Program	Urban Runoff/Storm Sewers	Siltation	Medium	2002	2003
Surface Water Assessment Program	Urban Runoff/Storm Sewers	Water/Flow Variability	Low	2002	2003

Table A1. (cont.)

**Aquatic Life Use
303(d) List of Streams and Sources of Impairments**

Data Source	Source	Cause	Priority	Year Listed	Targeted for TMDL
Named Streams: 02F - Neshaminy Creek					
	Segment ID: 20010426-1235-GLW	Miles Assessed: 5.2			
Surface Water Assessment Program	Land Development	Siltation	Medium	2002	
Surface Water Assessment Program	Agriculture	Siltation	Medium	2002	
	Segment ID: 20010525-1250-GLW	Miles Assessed: 7.6			
Surface Water Assessment Program	Urban Runoff/Storm Sewers	Siltation	Medium	2002	
	Segment ID: 20010525-1330-GLW	Miles Assessed: 5.4			
Surface Water Assessment Program	Urban Runoff/Storm Sewers	Siltation	Medium	2002	
	Segment ID: 467	Miles Assessed: 36.5			
Surface Water Assessment Program	Municipal Point Source	Nutrients	Medium	1996	2003
Surface Water Assessment Program	Other	Cause Unknown	Low	1996	2003
Surface Water Assessment Program	Municipal Point Source	Organic Enrichment/Low D.O.	Medium	1996	2003
Surface Water Assessment Program	Municipal Point Source	pH	Medium	1996	2003
	Segment ID: 980202-1313-GLW	Miles Assessed: 3.3			
Surface Water Assessment Program	Agriculture	Excessive Algal Growth	Medium	2002	2003
Surface Water Assessment Program	Agriculture	Siltation	Medium	2002	2003
Surface Water Assessment Program	Construction	Siltation	Medium	2002	2003
	Segment ID: 980205-1211-GLW	Miles Assessed: 1.5			
Surface Water Assessment Program	Land Development	Water/Flow Variability	Low	2002	
Surface Water Assessment Program	Urban Runoff/Storm Sewers	Flow Alterations	Low	2002	
	Segment ID: 980427-0945-GLW	Miles Assessed: 4.6			
Surface Water Assessment Program	Land Development	Siltation	Medium	2002	
	Segment ID: 980514-1004-GLW	Miles Assessed: 1.5			
Surface Water Assessment Program	Urban Runoff/Storm Sewers	Water/Flow Variability	Low	2002	
Surface Water Assessment Program	Urban Runoff/Storm Sewers	Siltation	Medium	2002	
	Segment ID: 980515-1347-GLW	Miles Assessed: 2			
Surface Water Assessment Program	Municipal Point Source	Water/Flow Variability	Low	2002	2003
Surface Water Assessment Program	Construction	Siltation	Medium	1996	2003
Surface Water Assessment Program	Municipal Point Source	Other Organics	Medium	1996	2003
	Segment ID: 980515-1348-GLW	Miles Assessed: 1.3			
Surface Water Assessment Program	Construction	Siltation	Medium	2002	
	Segment ID: 980609-1258-GLW	Miles Assessed: 3.2			
Surface Water Assessment Program	Urban Runoff/Storm Sewers	Water/Flow Variability	Low	2002	
	Segment ID: 980609-1259-GLW	Miles Assessed: 3.6			
Surface Water Assessment Program	Urban Runoff/Storm Sewers	Water/Flow Variability	Low	2002	
Surface Water Assessment Program	Municipal Point Source	Nutrients	Medium	2002	
	Segment ID: 980713-1351-GLW	Miles Assessed: 9.9			
Surface Water Assessment Program	Urban Runoff/Storm Sewers	Water/Flow Variability	Low	2002	2003
Surface Water Assessment Program	Agriculture	Nutrients	Medium	1996	2003
Named Streams: 02F - Neshaminy Creek, West Branch Neshaminy Creek					
	Segment ID: 980202-1040-GLW	Miles Assessed: 8.5			
Surface Water Assessment Program	Agriculture	Siltation	Medium	2002	2003
Surface Water Assessment Program	Land Development	Water/Flow Variability	Low	2002	2003
Surface Water Assessment Program	Agriculture	Excessive Algal Growth	Medium	2002	2003
Named Streams: 02F - North Branch Neshaminy Creek					
	Segment ID: 980210-1123-GLW	Miles Assessed: 3.3			
Surface Water Assessment Program	Upstream Impoundment	Siltation	Medium	2002	2003
Surface Water Assessment Program	Upstream Impoundment	Water/Flow Variability	Low	2002	2003
Named Streams: 02F - Pine Run					
	Segment ID: 980210-1240-GLW	Miles Assessed: 2.1			
Surface Water Assessment Program	Land Development	Siltation	Medium	2002	
Surface Water Assessment Program	Upstream Impoundment	Excessive Algal Growth	Medium	2002	
	Segment ID: 980210-1242-GLW	Miles Assessed: 1.3			
Surface Water Assessment Program	Land Development	Siltation	Medium	2002	
	Segment ID: 980211-1241-GLW	Miles Assessed: 5			
Surface Water Assessment Program	Land Development	Siltation	Medium	2002	

Table A1. (cont.)

Aquatic Life Use
303(d) List of Streams and Sources of Impairments

Data Source	Source	Cause	Priority	Year Listed	Targeted for TMDL
Named Streams: 02F - West Branch Neshaminy Creek					
Segment ID: 492 Miles Assessed: 0.1					
Surface Water Assessment Program	Municipal Point Source	Nutrients	Medium	1996	2003
Segment ID: 980202-1043-GLW Miles Assessed: 7.7					
Surface Water Assessment Program	Municipal Point Source	Excessive Algal Growth	Medium	2002	2003
Surface Water Assessment Program	Land Development	Water/Flow Variability	Low	2002	2003
Surface Water Assessment Program	Agriculture	Excessive Algal Growth	Medium	2002	2003
Surface Water Assessment Program	Municipal Point Source	Nutrients	Medium	1996	2003
Segment ID: 980202-1441-GLW Miles Assessed: 4.9					
Surface Water Assessment Program	Urban Runoff/Storm Sewers	Water/Flow Variability	Low	2002	
Surface Water Assessment Program	Land Development	Siltation	Medium	2002	
Segment ID: 980205-1330-GLW Miles Assessed: 1.8					
Surface Water Assessment Program	Urban Runoff/Storm Sewers	Siltation	Medium	2002	
Surface Water Assessment Program	Municipal Point Source	Flow Alterations	Low	2002	
Surface Water Assessment Program	Land Development	Water/Flow Variability	Low	2002	
Segment ID: 980205-1333-GLW Miles Assessed: 1.6					
Surface Water Assessment Program	Municipal Point Source	Flow Alterations	Low	2002	2003
Surface Water Assessment Program	Land Development	Water/Flow Variability	Low	2002	2003
Surface Water Assessment Program	Urban Runoff/Storm Sewers	Siltation	Medium	2002	2003
Segment ID: 980205-1430-GLW Miles Assessed: 5.1					
Surface Water Assessment Program	Urban Runoff/Storm Sewers	Water/Flow Variability	Low	2002	
Surface Water Assessment Program	Agriculture	Excessive Algal Growth	Medium	2002	
Surface Water Assessment Program	Land Development	Water/Flow Variability	Low	2002	
Surface Water Assessment Program	Agriculture	Siltation	Medium	2002	

As reported in greater detail in later sections, nutrients from municipal sources have been listed as the cause of impairment for a number of stream segments within the Neshaminy Creek watershed. The original 303(d) listings of most of these streams (ca. 1996) were based on a 1988 SERA survey, which is done to determine if nutrient loadings are impacting specific streams. In this case, nutrients from municipal treatment facilities were documented as causing organic enrichment problems in many streams within the watershed. As a result of this and water quality modeling studies conducted by USEPA Region 3 in 1982, all of the treatment facilities had nutrient limits included in their NPDES permits. Nutrient limits are applied April 1 through October 31.

Many changes have taken place in the watershed over the past 20 years. Within the past 10 years, municipal treatment plants have been upgraded to provide tertiary treatment, and the closing of some facilities and transference of waste flows to regional treatment facilities has occurred. There has also been a tremendous amount of growth. The amount of developed land, for example, has increased by about 20 percent in the watershed over the last decade. This represents drastic changes to the landscape and has a great effect on precipitation-driven runoff patterns. One significant problem in the watershed related to these changes is an increase in sedimentation problems due to increased stream bank erosion. With the increase in development comes an increase in the amount of impervious surface (pavement) which causes the water to run off the landscape at a much faster rate with greater force. This causes the stream banks to erode and deposit sediment in the stream channel. This sediment covers the stream bottom and reduces the habitat for aquatic organisms. For these reasons, many of the TMDLs developed for sub-areas of the Neshaminy Creek watershed are focused on sediment control. Nutrients from upland (i.e., nonpoint) sources have also been identified as problems in some stream reaches within the Neshaminy Creek watershed. These problems are primarily addressed in combination with point sources in Section D of this document.

Two stream segments in the watershed were also listed for Recreational Use impairments. These impairments are not addressed in this document and were handled as follows:

1) Segment 492 (West Branch Neshaminy Creek) is on the Section 303(d) list for Bacteria/Pathogens from Municipal Point Sources. This listing is erroneous in that the bacteria impairment is upstream of the municipal point source. The correct listing should be Source: Other Cause: Pathogens. BMPs implemented to meet the siltation TMDLs for the West Branch Neshaminy Creek (see Section C5.0) are expected to alleviate pathogen impairments in Segment 492.

2) Segment 477 (Park Creek) is on the 303(d) list for Pathogens from Municipal Point Sources. Bacteria samples were taken at three stations along Park Creek (Little State Road, Keith Valley Road and County Line Road). None of the geometric means violate criteria with the highest being 70.9. Steps will be taken to remove the pathogens listing for Segment 477.

B1.0 HYDROLOGIC/WATER QUALITY MODELING

B1.1 Overview of Modeling Approach

The TMDLs within the Neshaminy Creek watershed were primarily developed using the Generalized Watershed Loading Function (GWLF) and STREAMPLAN-PA models. GWLF is a watershed-based model that is used to estimate sediment and nutrient loads at the outlet of a given watershed (or sub-watershed), and is typically used to quantify pollutant loads from non-point sources. The STREAMPLAN-PA model is a version of the STREAMPLAN model adapted for use in Pennsylvania. It is an “in-stream” model that is typically used to estimate in-stream concentrations of various pollutants given specified point and non-point loads. The GWLF model was principally used in sub-areas where stream segments were listed as being impaired due to non-point sources (e.g., agriculture, urban areas, land development, etc.). For example, GWLF was used to estimate sediment loads to affected streams in all sub-areas where the listing was due to siltation from land development. In situations where streams were listed for impairments due to both point sources (i.e., municipal wastewater treatment plants) and non-point sources, both models were used. In this case, GWLF was first used to estimate non-point source loads to affected streams and STREAMPLAN-PA was subsequently used to combine these loads with point source discharge data to estimate in-stream nutrient concentrations. Both the GWLF and STREAMPLAN-PA models are described in greater detail in the following two sections. In one other instance (the TMDL assessment for Lake Galena), an additional model (BATHTUB) was used to evaluate lake water quality. This particular model is discussed more fully in Section C3.0.

B1.2 GWLF Model

The GWLF model provides the ability to simulate runoff, sediment, and nutrient (N and P) loadings from a watershed 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. It is a continuous simulation model, which uses daily time steps for weather data and water balance calculations. Monthly calculations are made for sediment and nutrient loads, based on the daily water balance accumulated to monthly values. GWLF is a combined 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 homogenous in regard 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 sub-surface loading, the model acts as a lumped parameter model using a water balance approach. No distinctly separate areas are considered for sub-surface flow contributions. Daily water balances are computed for an unsaturated zone as well as a saturated sub-surface 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 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 N and P 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 losses to the stream and are specified in terms of kilograms per month. Manured areas, as well as septic systems, can also 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. Sub-surface losses are calculated using dissolved N and P coefficients for shallow groundwater contributions to stream nutrient loads, and the sub-surface sub-model only considers a single, lumped-parameter contributing area. Evapotranspiration is determined using daily weather data and a cover factor dependent upon 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 of the equations used by the model can be viewed in Appendix A, GWLF Users Manual.

In addition to the original model algorithms described above, a streambank erosion routine was also implemented as part of the present study. This routine is based on an approach in which monthly streambank erosion is estimated by first calculating a watershed-specific lateral erosion rate (LER) for streams within the watershed. After a value for LER has been computed, the total sediment load generated via streambank erosion is then calculated by multiplying the above erosion rate by the total length of streams in the watershed, the average streambank height, and the average soil bulk density. More information on the specific details of this approach is provided in Appendix B.

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

The primary sources of data for analyses involving the use of GWLF were geographic information system (GIS) formatted databases. A specially designed interface was prepared by the Environmental Resources Research Institute (ERRI) of the Pennsylvania State University in ArcView (GIS software) to generate the data needed to run the GWLF model, which was developed by Cornell University. The new version of this model has been named AVGWLF (ArcView Version of the Generalized Watershed Loading Function)

In using this interface, the user is prompted to identify required GIS files and to provide other information related to “non-spatial” 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 (see Appendix A). For use in Pennsylvania, AVGWLF has been linked with statewide GIS data layers such as land use/cover, soils, topography, and physiography; and includes location-specific default information such as background N and P concentrations and cropping practices. Complete GWLF-formatted weather files are also included for eighty weather stations around the state. Table B1.1 lists the statewide GIS data sets and provides explanation of how they were used for development of the input files for the GWLF model.

Table B1.1 Description of GIS-based model input.

GIS Layer	Description
Censustr	Coverage of Census data including information on individual homes septic systems. The attribute <i>usew_sept</i> includes data on conventional systems, and <i>sew_other</i> provides data on short circuiting and other systems.
County	The County boundaries coverage lists data on conservation practices that provides C and P values in the Universal Soil Loss Equation (USLE).
Gwnback	A grid of background concentrations of N in groundwater derived from water well sampling.
Landuse5	Grid of the MRLC that has been reclassified into five categories. This is used primarily as a background.
Majored	Coverage of major roads. Used for reconnaissance of a watershed.
MCD	Minor civil divisions (boroughs, townships and cities).
Npdespts	A coverage of permitted point discharges. Provides background information and cross check for the point source coverage.
Padem	100 meter digital elevation model. This used to calculate landslope and slope length.
Palumrlc	A satellite image derived land cover grid which is classified into 15 different landcover categories. This dataset provides landcover loading rate 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 <i>rain_cool</i> and <i>rain_warm</i> are used to set recession coefficient
Pointsrc	Major point source discharges with permitted N and P loads.
Refwater	Shapefile of reference watersheds for which nutrient and sediment loads have been calculated.
Soilphos	A grid of soil phosphorous loads which has been generated from soil sample data. Used to help set phosphorus and sediment values.
Smallsheds	A coverage of watersheds derived at 1:24,000 scale. This coverage is used with the stream network to delineate the desired level watershed.
Statsgo	A shapefile of generalized soil boundaries. The attribute <i>mu_k</i> sets the k factor in the USLE. The attribute <i>mu_awc</i> is the unsaturated available capacity., and the <i>muhsg_dom</i> is used with landuse cover to derive curve numbers.
Strm305	A coverage of stream water quality as reported in the Pennsylvania's 305(b) report. Current status of assessed streams.
Surfgeol	A shapefile of the surface geology used to compare watersheds of similar qualities.
T9sheds	Data derived from a DEP study conducted at PSU with N and P loads.
Zipcode	A coverage of animal densities. Attribute <i>aeu_acre</i> helps estimate N & P concentrations in runoff in agricultural lands and over manured areas.
Weather Files	Historical weather files for stations around Pennsylvania to simulate flow.

B1.3 STREAMPLAN-PA

The point source modeling software used in this evaluation was derived from STREAMPLAN (A Spreadsheet Tool for River Environment Assessment, Management, and Planning). The STREAMPLAN model, developed by the International Institute for Applied Systems Analysis (IIASA) in Laxenburg, Austria, was designed as a decision support system to assist in the evaluation of water quality management strategies at the river basin level (De Marchi et al., 1996). In its original form STREAMPLAN allowed decision makers to investigate the implications of water management policy on water quality given set performance standards and financial resources.

STREAMPLAN is a spreadsheet-based computer software package that is used to model river basin water quality within the Microsoft EXCEL computing environment. The model is based upon widely used, simple mathematical representations of the hydrologic system in a steady-state formulation. The EXCEL spreadsheet format provides the user with greater flexibility and understanding of the processes involved when investigating in-stream hydrologic systems. The original version of STREAMPLAN contains four basic modeling components including: hydraulic, water quality, socio-economic, and optimization models.

A modified version of the STREAMPLAN software is currently being used to support Total Maximum Daily Load (TMDL) assessments requiring an analysis of in-stream conditions in impaired Pennsylvania watersheds. For the purposes of in-stream water quality modeling, the socio-economic and optimization routines have been removed from the STREAMPLAN framework. The model has been further adapted to calculate loads and in-stream concentrations at the monthly time step over a period of interest specified by the user. Additionally, a software link has been developed for the purpose of providing more precise estimates of “background” nutrient loads (i.e., non-point source loads) for STREAMPLAN based on output from AVGWLF.

Simply put, STREAMPLAN uses a “bucket” approach to model in-stream concentrations and loads of nutrients, sediment, dissolved oxygen, and carbonaceous biochemical oxygen demand. In STREAMPLAN, the watershed is modeled as a river network and a set of pollution inputs along it. The stream network is broken up into river reaches based upon the location of point sources, confluence of tributaries, and hydrologic characteristics. The model collects information for the upstream node of each river reach including:

1. Flow from upstream reaches
2. Flow from tributaries (if any) entering the river reach
3. Flow and concentration estimates of point source discharges
4. Flow and concentration estimates of non-point source inputs

Items 1,2, and 3 are calculated and provided by the STREAMPLAN modeling routines. Item 4, flow and concentration estimates of non-point source inputs, are generated for a sub-basin containing the river reach(s) using AVGWLF. The sub-basin estimate of non-point source pollution is then distributed to each river reach within the basin based upon a contributing area to total area ratio.

Using this information, along with the hydraulic characteristics and temperature of the river reach, the flow and pollutant concentration at the downstream node are calculated. This information is then passed to the upstream node of the next river reach, additional inputs are assessed, and the concentration and flow at the downstream node of that reach are calculated.

Two sub-models, discussed below, are used in conjunction with the hydraulic characteristics and pollution source information to estimate pollutant concentration and load in each river reach. These two models are the hydraulic sub-model and the water quality sub-model. The hydraulics routine is responsible for calculating mean velocity and mean depth in each river reach, while the water quality routine estimates both pollutant load and concentration within each river reach.

B1.3.1 The Hydraulic Sub-model

The hydraulic sub-model calculates mean stream velocity and depth in each river reach. This information can either be entered manually if detailed watershed information is available, or estimated using reach slope, reach length, average reach roughness coefficients, and cross-sectional area information. Calculation of the mean stream velocity and depth provide the required input for the water chemistry calculations conducted in the water quality sub-model.

In order to calculate in-stream concentrations and loads of various pollutants, the water quality sub-model requires information on the mean water depth in the reach. Mean water depth is defined as the ratio of water cross-sectional area to the top width (m), and is calculated using the following equation:

$$H = cQ^d$$

where:

- H = mean depth of water in the reach, defined as the ratio of water cross-sectional area to the top width (m)
- Q = discharge in the reach (m^3/s)
- c, d = coefficients

In the absence of field measurement, Q is derived by multiplying the reach cross-sectional area by stream velocity. Reach cross-sectional area is geometrically obtained using streambed width and mean water depth. Stream velocity is estimated using Manning's equation. Once these variables have been calculated for each river reach in the stream network, coefficients c and d are obtained by regression analysis, using these parameters. It is important to note that, in the absence of field measurement, estimates of velocity, stream geomorphology measurements, and discharge are derived by assuming that each river reach can be approximated by an idealized semi-circular or trapezoidal cross-section of the stream, which remains constant over the length of that reach.

B1.3.2 The Water Quality Sub-model

To simulate water quality conditions in each river reach, several additional assumptions are made, including:

1. River reach flow is uniform
2. Flows and emissions are steady
3. Complete mixing is assumed at all nodes (points between segments)
4. Only advective transport is supported; no dispersion is allowed
5. Distributed flows and emissions to the river reaches are not explicitly considered
6. Flow and water quality constituents are only calculated at the upstream and downstream nodes of each river reach

Pollutant concentrations at the downstream node of each river reach are calculated based upon these assumptions using standard constituent degradation equations such as those found in Thomann and Mueller (1987). For example, phosphorus concentration is computed using the following equation.

$$Z_1(t) = e^{(-\frac{k_1 t}{H})} Z_1(0)$$

where:

- $Z_1(t)$ = total phosphorus concentration at the downstream node of the river reach
- k_1 = loss rate of total phosphorus
- H = mean reach water depth
- t = travel time for the river reach, calculated by the hydraulics model using reach length and stream velocity
- $Z_1(0)$ = initial total phosphorus concentration, calculated at the upstream node of the river reach

The downstream node concentration estimates are then passed along with flow to the upstream node of the adjacent river reach. This information is combined with point and non-point source inputs to the reach and the calculations are repeated. For all pollutants considered, default values for loss rates, reaeration coefficients, transfer coefficients, etc. are based on those presented by Brown and Barnwell (1987). More detailed information on equations and procedures used within STREAMPLAN can be found at <http://www.iiasa.ac.at/Research/WAT/docs/stream.html>.

B1.4 Watershed Model Calibration

In the Neshaminy watershed as a whole, nutrient and sediment loads can originate from a variety of sources including upland erosion and runoff (particularly from agricultural activities and ongoing residential development), sub-surface flow (primarily from agricultural areas and septic systems), streambank erosion, and point source discharges. To adequately assess the various contributions and their resultant impacts on specific stream segments, AVGWLF and STREAMPLAN-PA were calibrated for this watershed using available water quality sample data for the period 4/93 to 3/99. To adequately represent point source discharges in the watershed, data obtained from DEP monthly discharge monitoring reports was used. In the calibration process, various model parameters were “fine-tuned” to more accurately depict critical model parameters. In particular, available groundwater quality sample data were used to adjust GWLF parameter values relating to sub-surface concentrations of nitrogen and phosphorus (GWN and

GWP, respectively) in various sub-areas of the watershed. Actual point source discharge data were also compiled from PaDEP monthly discharge reports to assist in the calibration process.

Figure B1.1 shows that portion of the watershed used in the calibration process (shaded) and the location of the WQN sampling station for which historical nutrient concentration and flow data were obtained in order to compute observed loads. Also shown in this figure are the locations of the point sources that discharge nitrogen and/or phosphorus to surface waters in the watershed. During the calibration step, AVGWLF was first used to estimate non-point source loads within each of the sub-basins depicted in Figure B1.1, and STREAMPLAN-PA was then used to combine these loads with point source discharge data to estimate in-stream nutrient concentrations. To better reflect localized conditions, groundwater sampling data available from DEP were used to estimate groundwater nitrogen and phosphorus concentrations within each sub-basin.

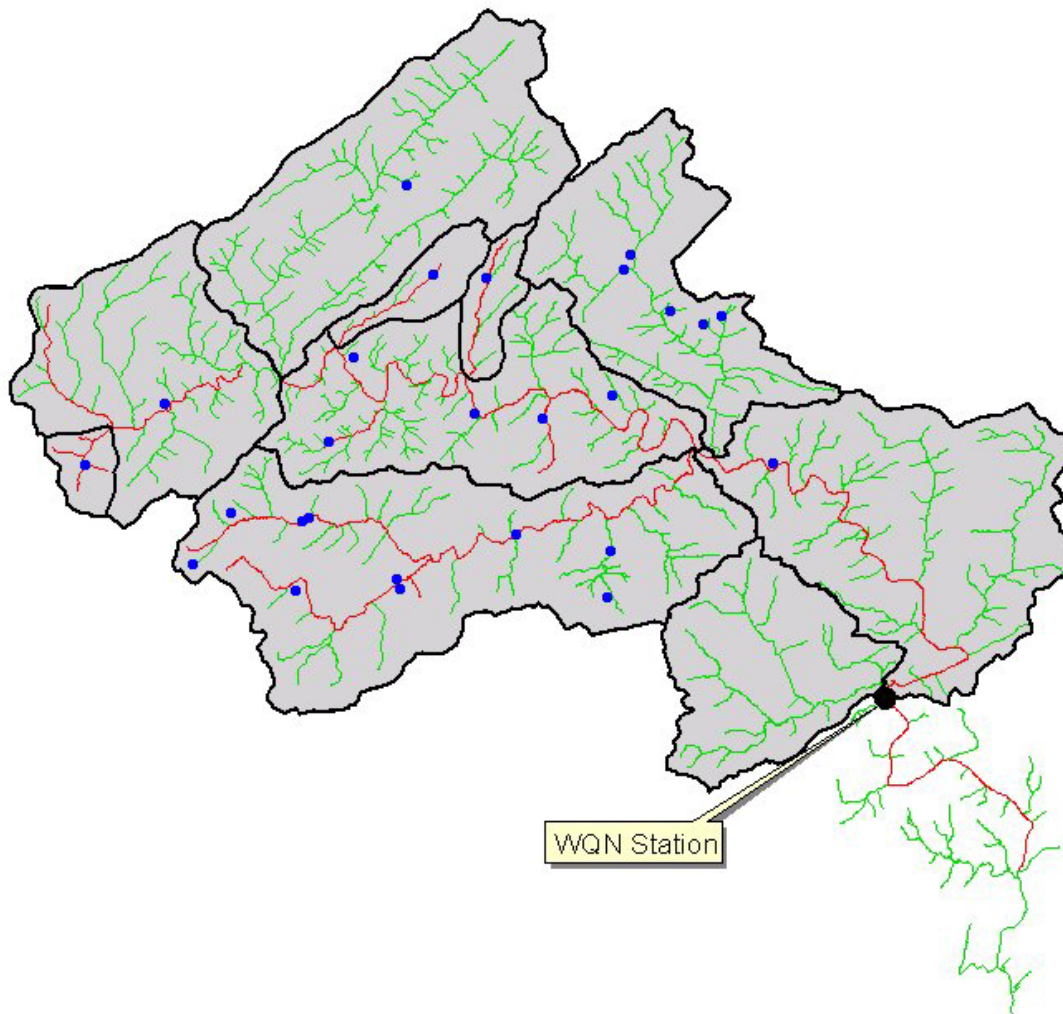


Figure B1.1. Locations of water quality sampling station, point source discharges (in blue), and sub-basins within the Neshaminy Creek watershed.

Figures B1.2 and B1.3 graphically show the calibration results for total phosphorus and total nitrogen, respectively. On a mean annual basis, approximately 760,000 kg (1,672,000 lbs) of total nitrogen and 62,000 kg (136,400 lbs) of total phosphorus are discharged at the WQN outlet. Table B1.2 provides a summary of the relative nutrient and sediment load contributions within the watershed by source.

As alluded to above, model calibration was performed in this watershed for the specific purpose of establishing loading rates from various sources more precisely than can be done solely using default data sets and parameter settings within AVGWLF. As with any model calibration, this can more easily be accomplished when existing water quality sampling and point source discharge data are available, as was the case for this study. After successful model calibration, the combined AVGWLF/STREAMPLAN-PA modeling approach could then be used to more precisely estimate in-stream nutrient concentrations at specific points within the watershed in order to address load reductions required in order to meet specified TMDL targets. More specific information on how this modeling approach was used to support point source-related TMDL assessments is provided in Section D.

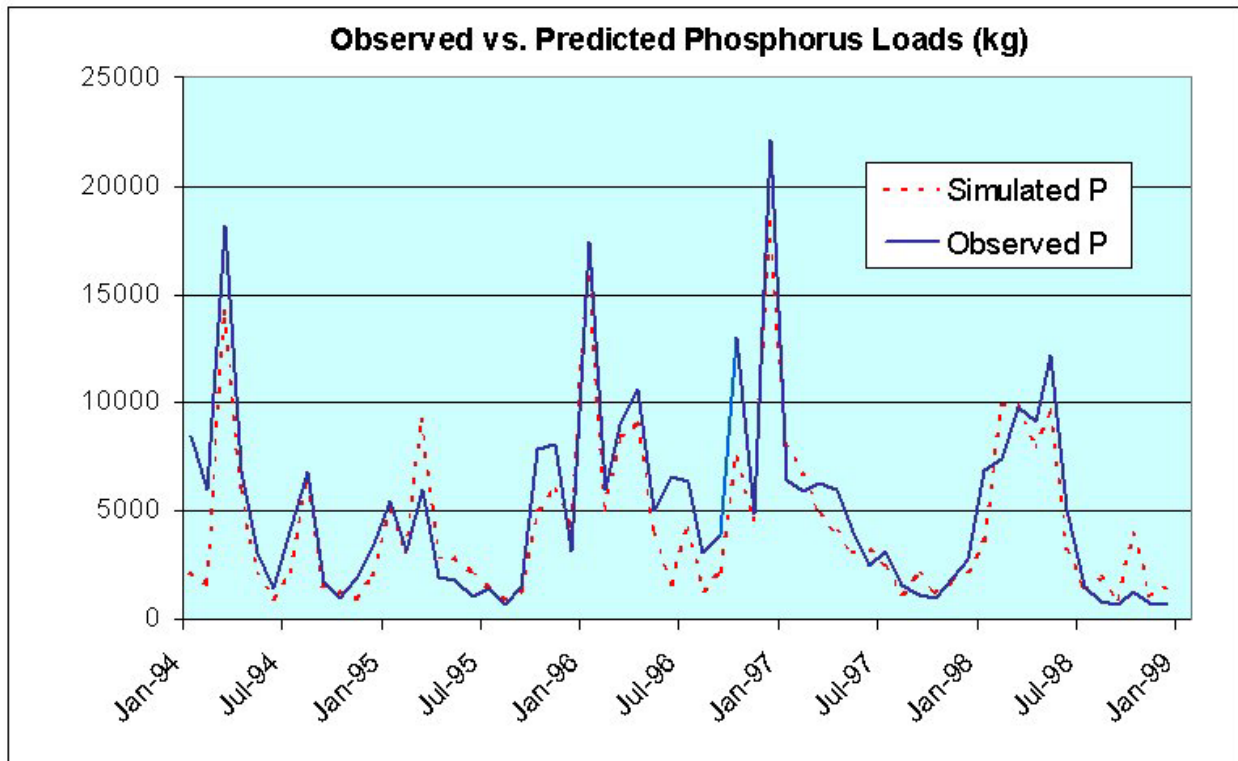


Figure B1.2. Comparison of observed vs. simulated total phosphorus loads for the Neshaminy Creek watershed.

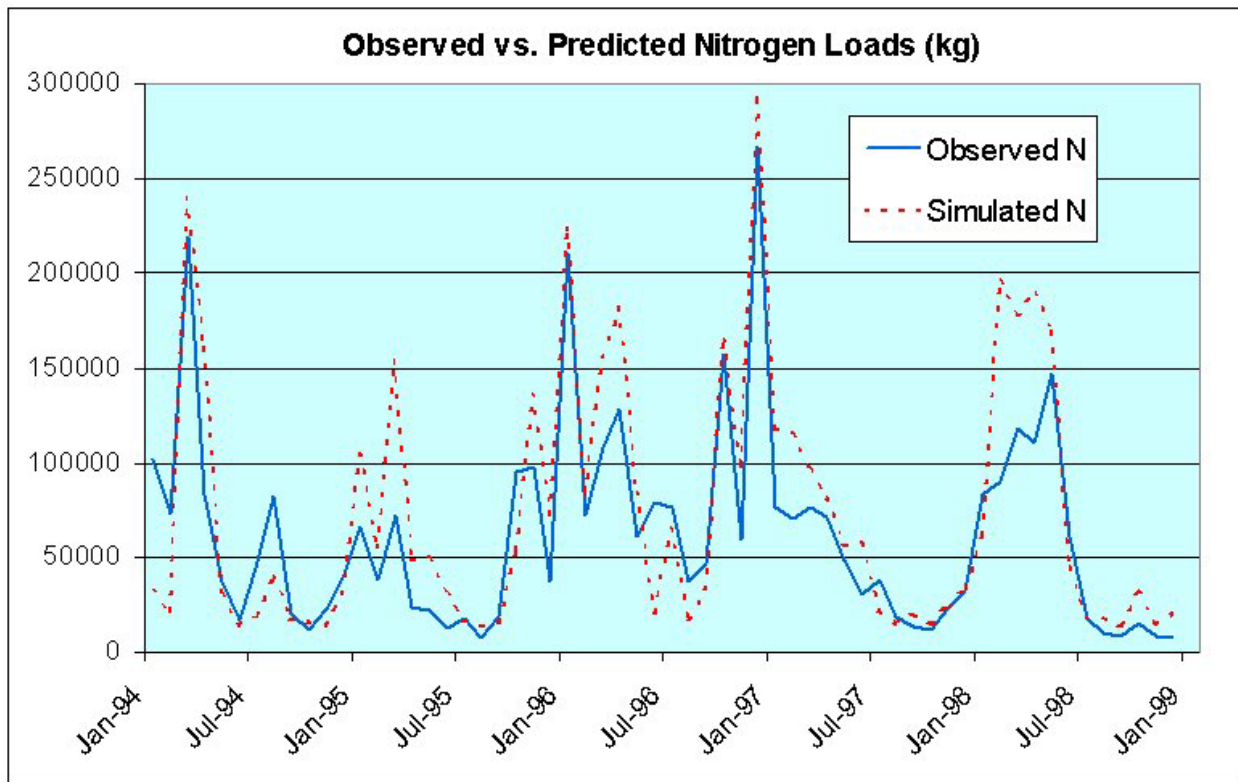


Figure B1.3. Comparison of observed vs. simulated total nitrogen loads for the Neshaminy Creek watershed.

Table B1.2. Relative contribution of nutrient and sediment loads by source.

Source	Percent of N	Percent of P	Percent of Sediment
Upland Erosion/Runoff	13.0	33.4	24.5
Streambank Erosion	7.2	24.2	75.5
Groundwater	51.7	17.4	-
Point Sources	21.2	24.8	-
Septic Systems	7.0	0.2	-

B1.5 Relationship Between Dissolved Oxygen Levels, Nutrient Loads and Organic Enrichment

As indicated earlier in Table A1, various streams within the Neshaminy Creek watershed have been listed as being impaired due to problems associated with dissolved oxygen levels, nutrient loads, and organic enrichment. In stream systems, elevated nutrient loads (nitrogen and phosphorus in particular) can lead to increased productivity of plants and other organisms (Novotny and Olem, 1994). Oxygen in water is used by plants (at night) and organisms in the stream. Excessive nutrient input can lead to elevated levels of productivity, which can subsequently lead to depressed dissolved oxygen levels when an abundance of aquatic life is drawing on a limited oxygen supply. Additional problems arise when these organisms die because the microbes that decompose this organic matter also consume large amounts of oxygen. A second effect of nitrogen (specifically ammonia) occurs when bacteria convert ammonia-nitrogen to nitrate-nitrogen. This process, called nitrification, also results in lower dissolved oxygen levels in streams.

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

In most fresh water bodies, phosphorus is the limiting nutrient for aquatic growth. In some cases, however, the determination of which nutrient is the most limiting is difficult to ascertain. For this reason, the ratio of the amount of N to the amount of P is often used to make this determination (Thomann and Mueller, 1987). If the N/P ratio is less than 10, nitrogen is deemed to be limiting; if the N/P ratio is greater than 10, phosphorus is considered to be the limiting nutrient. As described later in Section D2.0, most of the sub-basins used for TMDL assessment within the larger Neshaminy Creek watershed (see Figure D2.1) had N/P ratios much larger than 10, which implies that phosphorus is generally the limiting nutrient in this watershed. Consequently, it is expected that controlling the phosphorus load to streams in this watershed will limit plant growth and result in raising the dissolved oxygen level. Therefore, phosphorus loads (specifically in-stream concentrations) were targeted for reductions as described later in Section D.

C1.0 INTRODUCTION TO NONPOINT SOURCE-RELATED ASSESSMENTS

As described in previous sections, the AVGWLF modeling approach was used to quantify nutrient and sediment loads in sub-areas of the Neshaminy Creek watershed where stream segments were included on the State’s 303d list as being impaired primarily by non-point sources of pollution. In these cases, AVGWLF was used in one of two possible ways. In some cases, AVGWLF was used to estimate loads in an “impaired” watershed as well as a corresponding “reference” watershed for the purpose of establishing needed load reductions. In other cases, AVGWLF was used to calculate loads in the same watershed under two different time periods (i.e., “pre-problem” and “post-problem”), with the estimated load reduction based on the difference between the two time periods. More details on these two approaches are provided in later sections.

Figure C1 below shows the location of sub-watersheds within which AVGWLF was used to evaluate various nonpoint source-related stream impairments noted in Table A1. The particular TMDL assessments and subsequent load allocations associated with each of these sub-watersheds are detailed in the following sub-sections. In this figure, streams shown in red represent all of the impaired stream segments included in the 303d list given in Table A1.

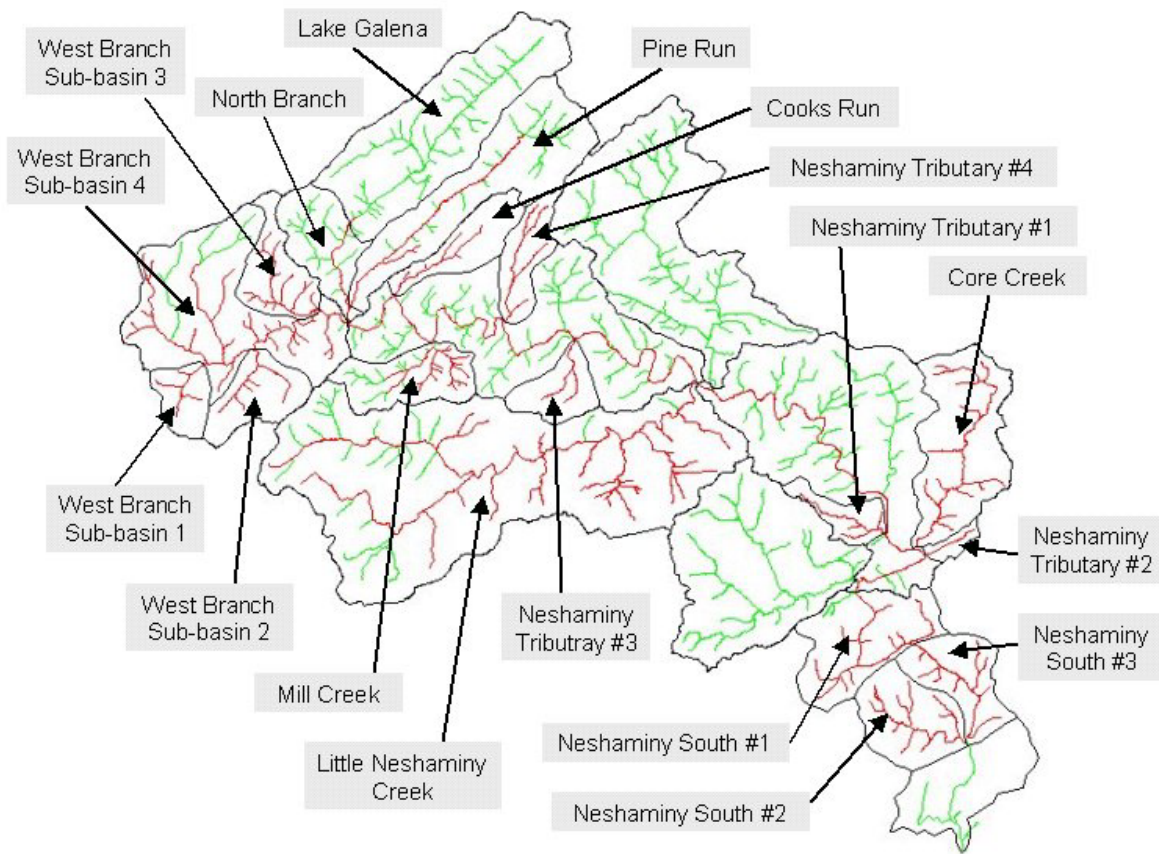


Figure C1. Location of sub-watersheds having nonpoint source-related impairments.