Total Maximum Daily Loads (TMDLs)
Pequea Creek, Lancaster County

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Susquehanna River Basin Commission
Water Quality and Monitoring Program

March 2, 2001
Revised June 16, 2006
Revised August 18, 2006

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EXECUTIVE SUMMARY

The Pequea Creek Watershed in Lancaster County covers 148 square miles (Figure 1). This report focuses on two parts of the watershed that have been targeted for TMDL development. State route 222 south of the City of Lancaster passes through the lower part of the watershed (Subbasin 1). State route 30 west of City of Lancaster passes through the upper part of the watershed (Subbasin 2). The protected uses of the watershed are water supply, recreation, and aquatic life. The aquatic life designation for the main stem Pequea Creek is primarily *warm water fishes*, with the headwater tributaries region designated *high quality, cold water fishes.*

The Susquehanna River Basin Commission (SRBC) developed Total Maximum Daily Loads, or TMDLs, for two subbasins of the Pequea Creek watershed to address the impairments noted on Pennsylvania's 1996 and 1998 303(d) lists and the 2000 305(b) report. Excess nutrient and sediment loads from agriculture are causing the impairments. The nutrient portion of the TMDL focuses on control of phosphorus

Pennsylvania does not currently have water quality criteria for sediment or nutrients. For this reason, Pennsylvania's Department of Environmental Protection (Pa. DEP) developed a reference watershed approach to identify the TMDL endpoints, or water quality objectives, for phosphorus and sediment in the impaired segments of the Pequea Creek Watershed. By comparison to a similar non-impaired watershed, we estimated that the amount of phosphorus loading that will meet the water quality objectives for Pequea Creek is approximately 35,518 lbs/yr (pounds per year) and 41,020 lbs/yr for Subbasins 1 and 2 respectively (Table 1). Sediment loading must be limited to 7,248,622 lbs/yr and 8,371,424 lbs/yr for Subbasins 1 and 2 respectively (Table 1). When these values are met, Pequea Creek will support its aquatic life uses.

Table 1. TMDL Endpoints for the Pequea Creek Watershed

Pollutant	Current Loading (lbs/yr)	TMDL (lbs/yr)	Percent Reduction in Loads Needed to Meet TMDL
Subbasin 1			
Phosphorus	82,810	35,518	57%
Sediment	42,590,387	7,248,622	83%
Subbasin 2			
Phosphorus	69,004	41,020	40%
Sediment	35,218,566	8,371,424	76%

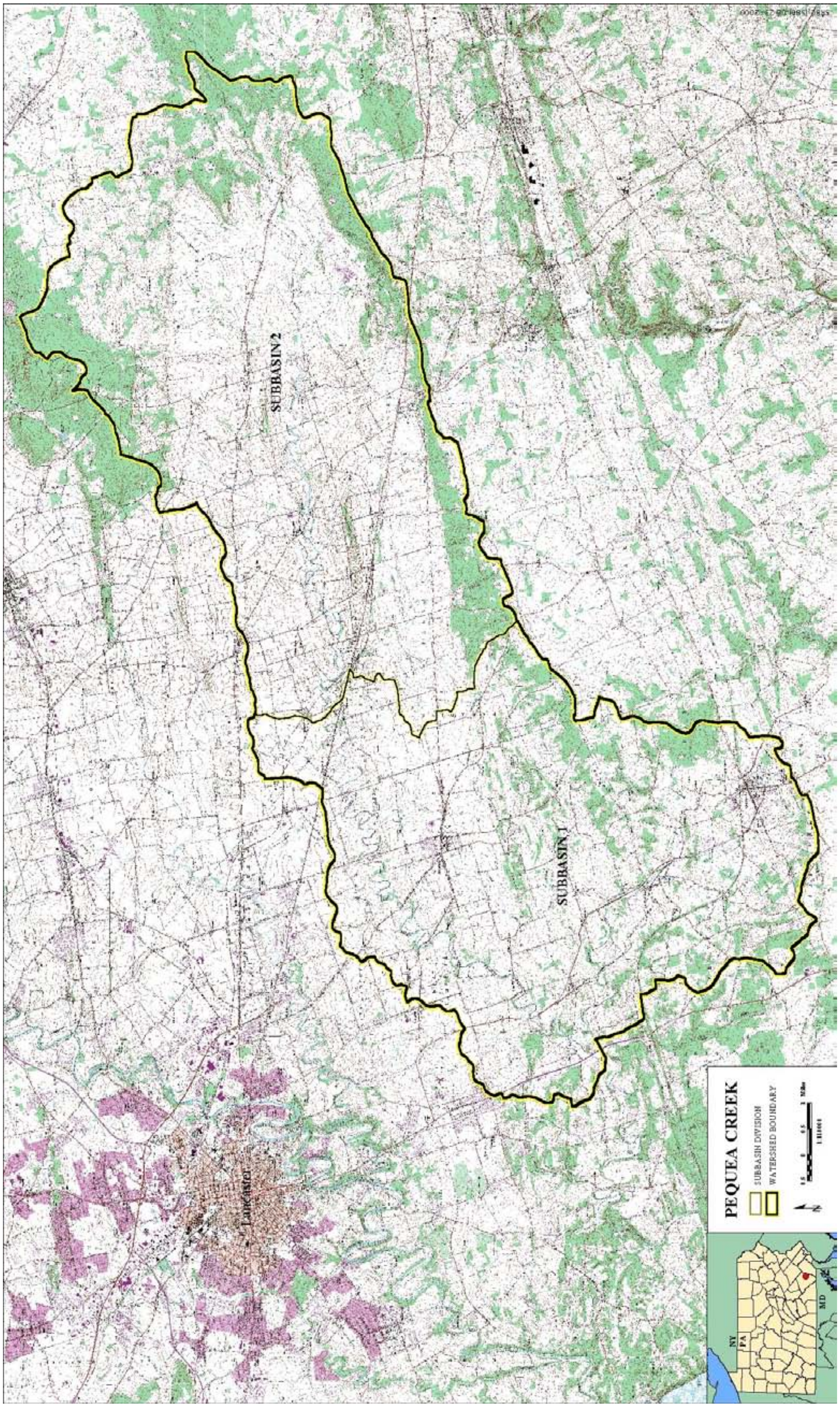

Figure 1. – Location map for Pequea Creek.

The TMDLs are allocated to runoff from agriculture and developed areas (Load Allocations - LAs), with 4.6 to 10% of the allowable loading reserved as a margin of safety (MOS). The TMDLs cover a total of 109 stream miles within Pequea Creek Watershed. For Subbasin 1, the TMDL establishes a reduction for phosphorus loading of 57% from the current yearly loading of 82,810 pounds and a reduction in sediment loading of 83% from the current yearly loading of 42,590,387 pounds. For Subbasin 2, the TMDL establishes a reduction for phosphorus loading of 40% from the current yearly loading of 69,004 pounds and a reduction in sediment loading of 76% from the current yearly loading of 35,218,566 pounds.

More complete discussions of the Pequea Creek TMDL and TMDLs in general are contained in the Information Sheet and the body of this document.

INTRODUCTION

Total Maximum Daily Loads, or TMDLs, were developed for the Pequea Creek watershed to address the impairments noted on Pennsylvania's 1996 and 1998 303(d) lists, and the 2000 305(b) report (Table 2). Figures 2 and 3 show the impaired segments within Subbasins 1 and 2.

The main stem of Pequea Creek was placed on the 1996 303(d) List based on an aquatic biological survey performed by the Susquehanna River Basin Commission (SRBC) in 1985. The survey was part of the SRBC Subbasin Survey Program (McMorran, 1986). In 1991, the U.S. Department of Agriculture (USDA) initiated a Water-Quality Hydrologic Unit Project in the Pequea-Mill Creek watersheds in Lancaster County. Aquatic biological surveys performed for the study increased the impairments listed on the 1998 303(d) list for Pequea Creek. An additional 4.21 miles of the main stem was listed as impaired. An unnamed tributary to Pequea Creek was also listed as impaired. In 1999, as part of Pa. DEP's Unassessed Waters Program, the remaining 99.25 stream miles were listed as impaired. All the biological surveys included kick screen sampling of benthic macroinvertebrates, and habitat surveys. Benthic macroinvertebrates were identified to the family level in the field.

The biological surveys indicated impairment due to excessive amounts of sediment and nutrients, organic enrichment, and low dissolved oxygen (DO). Agricultural land use in the watershed is the cause for the violations of the aquatic life use, due to the excessive amounts of phosphorus and sediment delivered to the stream.

The primary method that the Pa. DEP has adopted for evaluating waters changed between the publication of the 1996 and 1998 303(d) lists. Pa. DEP is now using a modification of U.S. Environmental Protection Agency's (U.S. EPA) Rapid Bioassessment Protocol II (RPB-II) as the primary mechanism to assess Pennsylvania's unassessed waters. The assessment method requires selecting stream sites that would reflect impacts from surrounding land uses that are representative of the stream segment being assessed. The biologist selects as many sites as necessary to establish an accurate assessment for a stream segment. At each site, a biological assessment is conducted using the modified RBP II method. The length of the stream segment assessed can vary between sites. There are several factors that determine site location and how long a segment can be. These factors include distinct changes in stream characteristics, surface geology, riparian land use, and the pollutant that is causing impairment.

For the purpose of TMDL development, it is often necessary to aggregate 303(d) listed stream segments. The primary reason to address multiple segments is compatibility with data used in TMDL analysis. For these TMDL analyses, the primary data sources are geographic information system (GIS) derived data. The land cover data set used for this analysis is represented by 30 meter squares. If the stream segment area for TMDL development is too small, error is introduced by using the data beyond its capability. For this reason, we have aggregated segments listed in the Pequea Creek watershed. This results in completing TMDLs for several segments, although the model analyses were completed as two watershed areas.

Neither Pennsylvania nor the U.S. EPA currently has water quality criteria for sediment or nutrients. Therefore, Pa. DEP developed a reference watershed approach to identify the TMDL endpoints or water quality objectives for nutrients and sediment in the impaired segments of the Pequea Creek Watershed. The nutrient portion of the TMDL for this watershed is phosphorus.

The Pequea Creek Watershed TMDL Information Sheet that is attached to this document provides a primer for TMDLs (*What are they and why are we doing them?*) and water quality standards (*What makes up a water quality standard?*). Appendices A and B provide information on the method being used by Pennsylvania for establishment of TMDLs.

Table 2. List of Impaired Streams with Designated Allocation Units

Segment ID	Stream Code	Year Listed	Stream Name (Designated Use)	Source Code	Cause Code	Miles Degraded	Allocation Unit (Subbasin)
990525-1605-BPG	7488	2000	Little Beaver Creek (TSF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	5.83	5 and 6 (1)
990525-1605-BPG	7492	2000	Little Beaver Creek/Unnamed Tributary (TSF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	.03	5 (1)
990526-1005-BPG	7492	2000	Little Beaver Creek/Unnamed Tributary (TSF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	.92	5 (1)
990525-1605-BPG	7493	2000	Little Beaver Creek/Unnamed Tributary (TSF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	1.1	5 (1)
990525-1605-BPG	7494	2000	Little Beaver Creek/Unnamed Tributary (TSF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	.95	5 (1)
990525-1605-BPG	7498	2000	Little Beaver Creek/Unnamed Tributary (TSF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	1.22	6 (1)
990614-1005-BPG	7500	2000	Pequea Creek/Unnamed Tributary (WWF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	.82	10 (1)
990614-1005-BPG	7501	2000	Pequea Creek/Unnamed Tributary (WWF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	.99	10 (1)

Table 2. List of Impaired Streams with Designated Allocation Units							
Segment ID	**Stream Code**	**Year Listed**	**Stream Name (Designated Use)**	**Source Code**	**Cause Code**	**Miles Degraded**	**Allocation Unit (Subbasin)**
990614-1005-BPG	7502	2000	Pequea Creek/Unnamed Tributary (WWF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	1.22	10 (1)
990614-1005-BPG	7450	1996 (Miles added in 1998)	Pequea Creek (WWF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	8.55	10 (1)
990614-1005-BPG	7503	2000	Pequea Creek/Unnamed Tributary (WWF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	.49	10 (1)
990614-1005-BPG	7504	2000	Pequea Creek/Unnamed Tributary (WWF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	1.29	10 (1)
990614-1135-BPG	7505	2000	Pequea Creek/Unnamed Tributary (WWF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	1.42	8 (1)
990614-1135-BPG	7506	1996	Pequea Creek/Unnamed Tributary (WWF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	1.07	9 (1)
990614-1135-BPG	7507	2000	Pequea Creek/Unnamed Tributary (WWF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	1.22	8 (1)
990614-1135-BPG	7508	2000	Pequea Creek/Unnamed Tributary (WWF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	1.73	9 (1)
990614-1135-BPG	7509	2000	Pequea Creek/Unnamed Tributary (WWF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	.55	9 (1)
990614-1135-BPG	7510	2000	Pequea Creek/Unnamed Tributary (WWF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	1.65	9 (1)

Table 2. List of Impaired Streams with Designated Allocation Units							
Segment ID	**Stream Code**	**Year Listed**	**Stream Name (Designated Use)**	**Source Code**	**Cause Code**	**Miles Degraded**	**Allocation Unit (Subbasin)**
990525-1605-BPG	7495	2000	Calamus Run (TSF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	3.58	7 (1)
990525-1605-BPG	7496	2000	Calamus Run/Unnamed Tributary (TSF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	.9	7 (1)
990525-1605-BPG	7497	2000	Calamus Run/Unnamed Tributary (TSF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	.86	7 (1)
990609-1405-BPG	7477	2000	South Fork Big Beaver Creek (TSF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	2.4	3 (1)
990609-1405-BPG	7478	2000	South Fork Big Beaver Creek/Unnamed Tributary (TSF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	1.87	3 (1)
990609-1405-BPG	7480	2000	South Fork Big Beaver Creek/Unnamed Tributary (TSF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	.74	3 (1)
990609-1405-BPG	7481	2000	South Fork Big Beaver Creek/Unnamed Tributary (TSF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	.69	3 (1)
990608-1335-BPG	7499	2000	Walnut Run (WWF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	3.18	11 (1)
990609-1405-BPG	7471	2000	Big Beaver Creek (TSF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	2.03	4 (1)
990610-1435-BPG	7471	2000	Big Beaver Creek (TSF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	.78	4 (1)

Table 2. List of Impaired Streams with Designated Allocation Units							
Segment ID	**Stream Code**	**Year Listed**	**Stream Name (Designated Use)**	**Source Code**	**Cause Code**	**Miles Degraded**	**Allocation Unit (Subbasin)**
990610-1435-BPG	7476	2000	Big Beaver Creek/Unnamed Tributary (TSF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	1.96	2 (1)
990609-1405-BPG	7479	2000	South Fork Big Beaver Creek/Unnamed Tributary (TSF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	2.81	3 (1)
990614-1135-BPG	7450	1998	Pequea Creek (WWF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	10.91	9,10 (1) 13 (2)
990615-1005-BPG	7513	2000	Eshleman Run (CWF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	1.24	1 (2)
990628-1105-BPG	7523	2000	Houston Run (CWF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	4.53	3 (2)
990615-1005-BPG	7515	2000	Londonland Run (CWF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	.84	2 (2)
990622-1520-BPG	7450	1998	Pequea Creek (HQ-CWF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	4.53	7 (2)
990615-1005-BPG	7515	2000	Londonland Run (CWF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	.84	2 (2)
990616-1005-BPG	7450	1998	Pequea Creek (WWF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	3.11	13 (2)
990614-1135-BPG	7522	2000	Pequea Creek/Unnamed Tributary (CWF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	1.76	11 (2)

Table 2. List of Impaired Streams with Designated Allocation Units							
Segment ID	**Stream Code**	**Year Listed**	**Stream Name (Designated Use)**	**Source Code**	**Cause Code**	**Miles Degraded**	**Allocation Unit (Subbasin)**
990628-1205-BPG	7531	2000	Pequea Creek/Unnamed Tributary (CWF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	3.86	4 (2)
990628-1205-BPG	7533	2000	Pequea Creek/Unnamed Tributary (CWF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	.9	4 (2)
990616-1005-BPG	7534	2000	Pequea Creek/Unnamed Tributary (CWF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	3.3	8 (2)
990622-1520-BPG	7542	2000	Pequea Creek/Unnamed Tributary (HQ-CWF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	3.03	7 (2)
990616-1435-BPG	7525	2000	Richardson Run (HQ-CWF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	4.09	9 (2)
990616-1435-BPG	7526	2000	Richardson Run/Unnamed Tributary (HQ-CWF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	1	10 (2)
990616-1435-BPG	7527	2000	Richardson Run/Unnamed Tributary (HQ-CWF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	3.01	9 (2)
990616-1435-BPG	7528	2000	Richardson Run/Unnamed Tributary (HQ-CWF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	.93	9 (2)
990616-1435-BPG	7524	2000	Umbles Run (HQ-CWF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	4.05	10 (2)
990616-1435-BPG	7529	2000	Umbles Run/Unnamed Tributary (HQ-CWF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	.69	10 (2)

Table 2. List of Impaired Streams with Designated Allocation Units							
Segment ID	**Stream Code**	**Year Listed**	**Stream Name (Designated Use)**	**Source Code**	**Cause Code**	**Miles Degraded**	**Allocation Unit (Subbasin)**
990616-1435-BPG	7530	2000	Umbles Run/Unnamed Tributary (HQ-CWF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	1.1	10 (2)
990614-1135-BPG	7511	2000	Walnut Run (WWF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	2.42	12 (2)
990614-1135-BPG	7512	2000	Walnut Run/Unnamed Tributary (WWF)	Agriculture	Nutrients Organic Enrichment/Low D.O. Siltation	.84	12 (2)

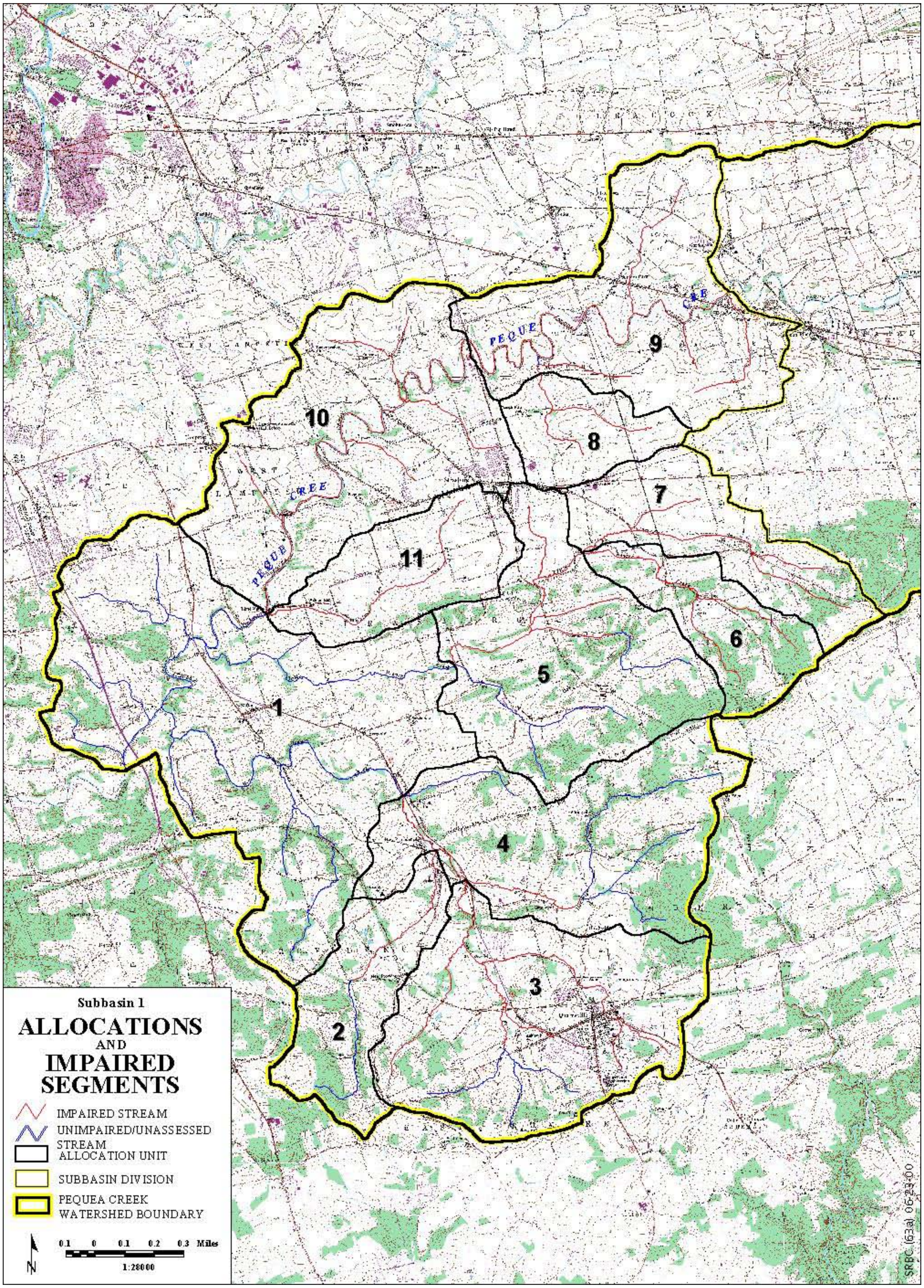

Figure 2. - Map showing impaired streams and allocation units for Subbasin 1.

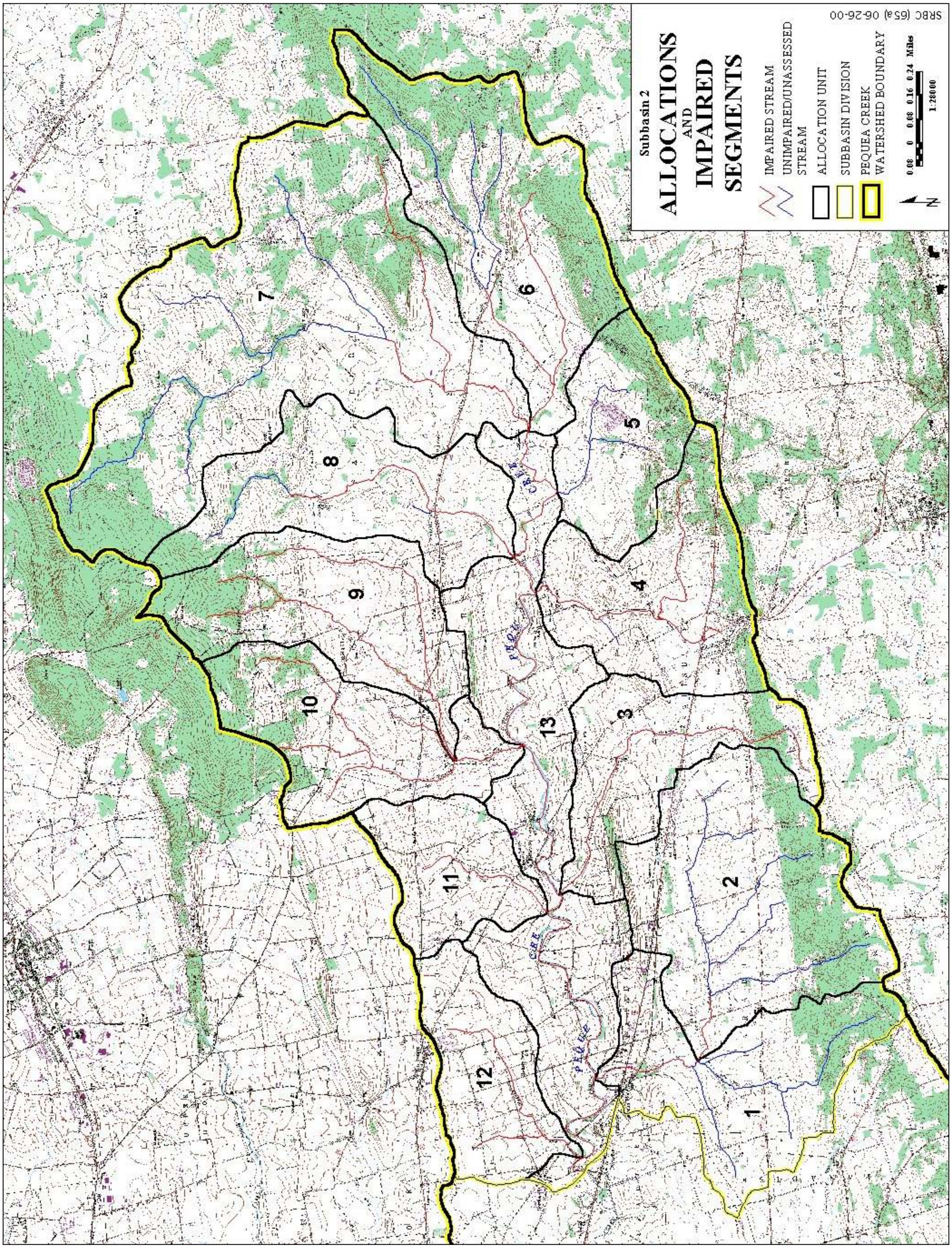

Figure 3. - Map showing impaired streams and allocation units for Subbasin 2.

TMDL ENDPOINTS

The TMDLs developed for the Pequea Creek watershed address sediment and nutrients. Because neither Pennsylvania nor EPA has water quality criteria for sediments or nutrients, a method was developed to determine water quality objectives for these parameters that would result in the impaired stream segments attaining their designated uses. The method employed for these TMDLs is termed the "Reference Watershed Approach."

The Reference Watershed Approach compares two watersheds, one attaining its uses and one that is impaired based on biological assessment. Both watersheds must have similar land cover and land use characteristics. Other features such as base geologic formation should be matched to the extent possible; however, most variations can be adjusted in the model. The objective of the process is to reduce the loading rates of nutrients and sediment in the impaired stream segment to a level equivalent to, or slightly lower than, the loading rates in the reference stream segment. This load reduction will allow the biological community to return to the affected stream segments. The TMDL endpoints established for this analysis were determined using Conococheague Creek as the reference watershed. The Conococheague Creek Watershed lies within the Potomac River Basin, in Franklin County, Pennsylvania. These endpoints are discussed in detail in the "Selection of the Reference Watershed" section.

Nutrient Loads and Organic Enrichment in Stream Systems

As indicated earlier, Pequea Creek was listed as being impaired due to problems associated with nutrient loads and suspended sediments. In stream systems, elevated nutrient loads (nitrogen and phosphorus) can lead to increased productivity of plants and other organisms (Novotny and Olem, 1994). Additional problems can also occur if nutrient loads are not reduced.

Typically, the quantities of trace elements are plentiful in aquatic ecosystems; 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 (Novotny and Olem, 1994). In most efforts to control eutrophication processes in water bodies, emphasis is placed on the limiting nutrient. In some instances, this may not always be the case. 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.

The ratio of the amount of nitrogen (N) to the amount of phosphorus (P) is often used to determine which nutrient is limiting (Thomann and Mueller, 1987). If the N/P ratio is less than 10, nitrogen is limiting; if the N/P ratio is greater than 10, phosphorus is the limiting nutrient. A ratio equal to 10 indicates neither phosphorus nor nitrogen is limiting. Water quality data were collected at the mouth of Pequea Creek as part of Pennsylvania's Water Quality Network (WQN) Program from 1990-1995. Some sampling events had missing data which precluded the calculation of a total nitrogen value, but the 48 samples with enough data to calculate the TN:TP ratio averaged 49.86 indicating a strong phosphorus limitation. Two of the 48 samples had

TN:TP ratios below 10; however, the measured TP at those times were 1.26 mg/l and 1.44 mg/l also indicating excessive in-stream phosphorus. Based on the water quality data, phosphorus was deemed to be the limiting nutrient and targeted for reductions in this TMDL.

SELECTION OF THE REFERENCE WATERSHED

The reference watershed approach was used to estimate the appropriate reduction of phosphorus and sediment loading necessary to restore healthy aquatic communities to the Pequea Creek watershed. This approach is based on selecting a non-impaired watershed ("reference") and determining its current loading rates for the pollutants of interest. The objective of the process is to reduce loading rates of those pollutants identified as causing impairment to a level equivalent to the loading rates in the reference watershed. Achieving the appropriate load reductions should allow the return of a healthy biological community to affected stream segments.

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

A watershed that would satisfy all the characteristics mentioned above could not be found in the same physiographic province as Pequea Creek due to the following reasons:

1) Not all stream segments in the Piedmont Physiographic Province where Pequea Creek watershed is located have been assessed.

2) All watersheds that have similar levels of agricultural land use and geologic rock type distributions as Pequea Creek watershed are also impaired.

The watershed used as a reference for the Pequea Creek Watershed was obtained by screen-digitizing a subwatershed of the Conococheague Creek watershed (Figure 4). This watershed is located in the Ridge and Valley Province in State Water Plan (SWP) Basin 13C, Franklin County. The digitized (reference) watershed is referred in this report as "Conococheague watershed". Table 3 compares the two watersheds in terms of their size, location, and other physical characteristics. Most of Conococheague stream segments have been assessed and were found to be unimpaired.

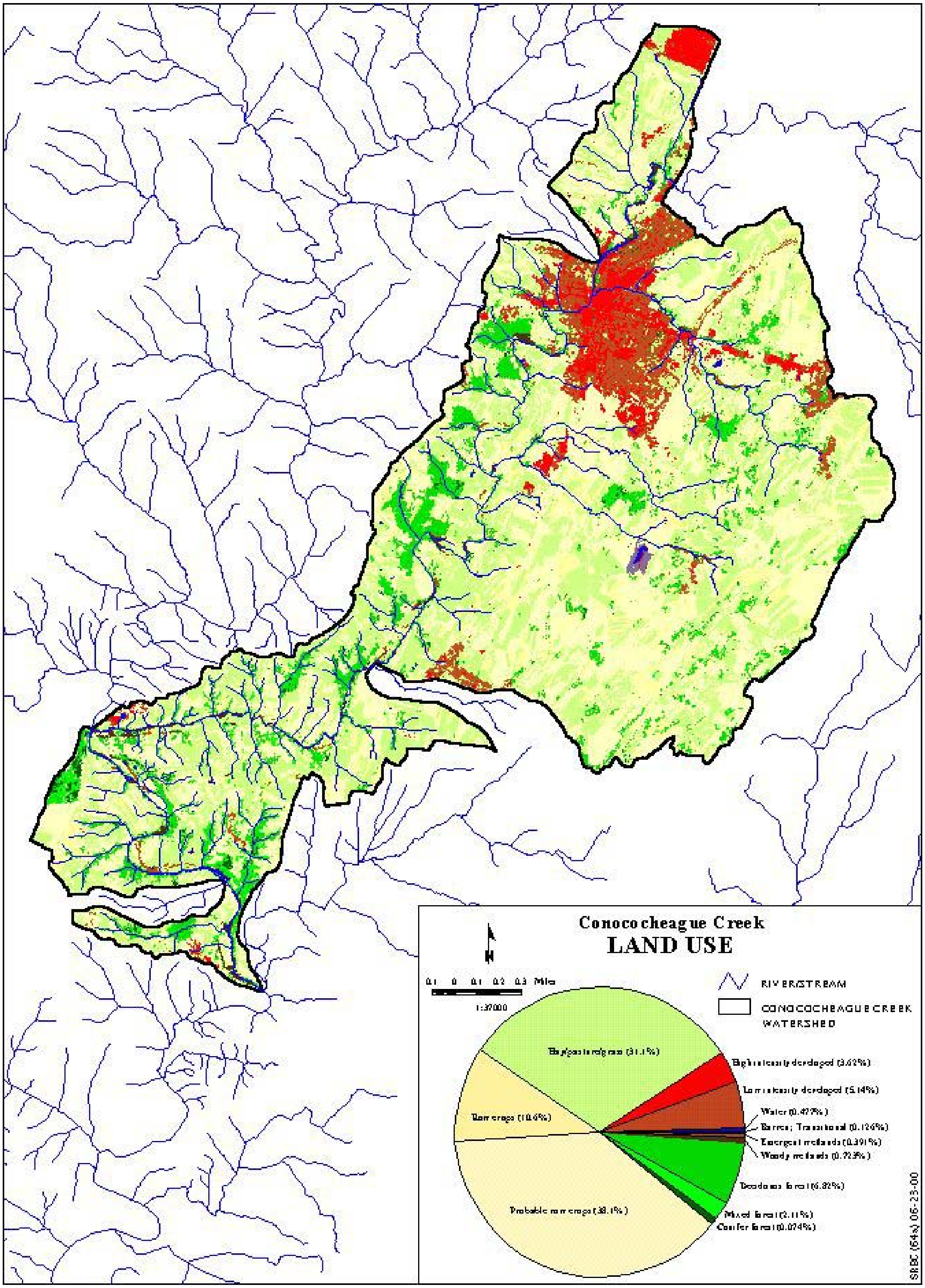

Figure 4. - Map showing land use for the Conococheague Watershed.

The analysis of value counts for each pixel of the MRLC grid revealed that land cover/use distributions in both watersheds are similar. The agricultural land use, which is the source of impairment in Pequea Creek watershed, accounts for 86% of the total land area as compared to 84% in Conococheague watershed. The surficial geologies of the Pequea Creek and Conococheague watersheds were also compared and appear to produce reasonably a good match. The geology of Pequea Creek Watershed consists primarily of carbonate (56%) and sedimentary (12%) rock, while Conococheague watershed is predominantly carbonate (63%) and sedimentary (12%) rock. The bedrock geology affects primarily surface runoff and background nutrient loads through its influences on soils and landscape as well as fracture density and directional permeability. A look at these attributes in Table 3 indicates that these watersheds also compare very well in terms of average precipitation and soil K factor. The portion of Conococheague Creek Watershed selected for the analyses is approximately 62 square miles. The Pequea Creek Watershed was subdivided into two subbasins (Subbasin 1 and Subbasin 2) so it was more comparable to the size of the Conococheague.

Table 3. Comparison Between Pequea Creek and Conococheague Watersheds

Attribute	**Pequea Creek**	**Conococheague**
Physiographic Province	Piedmont	Ridge and Valley
Area (square miles)	56.9 (Subbasin 1) 65.6 (Subbasin 2)	62.6
Predominant Land Use		
	Agriculture (86%)	Agriculture (84%)
Predominant Geology		
	Carbonate (56)%	Carbonate (63%)
	Sedimentary (12%)	Sedimentary (12%)
Soils		
Dominant HSG	B (85%), C (15%)	B(13%), C (87%)
K Factor	0.30	0.28
20-Year Average Rainfall (in)	43.5	39.3
20-Year Average Runoff (in)	2.6	4.3

DATA COMPILATION AND MODEL OVERVIEW

The TMDLs were developed using the GWLF model. The GWLF model provides the ability to simulate runoff, sediment, and nutrient loadings from 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 that 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 homogeneous 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 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 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 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 oxygen 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. Subsurface losses are calculated using dissolved N and P coefficients for shallow groundwater contributions to stream nutrient loads. The subsurface 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.

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.

GIS BASED DERIVATION OF INPUT DATA

The primary sources of data for this analysis were geographic information system (GIS) formatted databases. A specially designed interface was prepared by the Environmental Resources Research Institute of the Pennsylvania State University in ArcView (GIS software) to generate the data needed to run the GWLF model. The GWLF model was originally 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 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-eight weather stations around the state. Table 4 lists the GIS data sets and provides an explanation of how they were used for development of the input files for the GWLF model.

Table 4. GIS Data Sets Used by the AVGWLF Model	
Censustr	Coverage of census data including information on individual home 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 that provide 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 is used to calculate slope and aspect.
Palumrlc	A satellite image derived land cover grid that 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 *rain_cool* and *rain_warm* 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 have been generated from soil sample data. Used to help set phosphorus and sediment values.
Smallsheds	A coverage of watersheds at the 1:24,000 This coverage is used with the stream network to delineate the desired level watershed.
Statsgo	A shapefile 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 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 PA DEP study conducted at PSU with N and P loads.
Zipcode	A coverage of animal densities. Attribute *aeu_acre* 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.

As described in the Data Compilation and Model Overview section, 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 within the watershed. If point source discharges are identified, and the corresponding nutrient loads are quantified, these loads are summed to represent the total pollutant loads for the watershed.

In the GWLF model, the nonpoint source (or "background") load calculated is affected by terrain conditions such as amount of agricultural land, land slope, and inherent soil erodibility. It is also affected by farming practices utilized in the area, as well as by background concentrations of nutrients (i.e., N and P) in soil and groundwater. Various parameters are included in the model to account for these conditions and practices. Some of the more important parameters are summarized below:

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

Curve number: This 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 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, the crops grown and the cultivation practices utilized largely control this factor. 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 utilized in agricultural areas. Values range from 0 to 1.0, with larger values indicating greater potential for erosion.

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

Unsaturated available water-holding capacity: This 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 varies according to land use/cover type, and reasonable values have been established in the literature. This rate, reported in mg/l, can be re-adjusted 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 mg/l, can be re-adjusted based on local conditions such as rates of fertilizer application and farm animal populations.

Nutrient concentrations in runoff over manured areas: These are user-specified concentrations for N and P 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 are based on values obtained from the literature. They also can be adjusted based on local conditions such as rates of manure application or farm animal populations.

Nutrient build-up in non-urban areas: In GWLF, rates of build-up for both N and P have to be specified. In Pennsylvania, this is estimated using historical information on atmospheric deposition.

Background N and P concentrations in groundwater: Subsurface concentrations of nutrients (primarily N) contribute to the nutrient loads in streams. In Pennsylvania, these concentrations are estimated using recently published data from USGS.

Background N and P concentrations in soil: Since 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 upon manure loading rates and farm animal populations.

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 Users Guide provided in Appendix A of this document. Specific details in this guide that describe equations and typical parameter values used can be found on pages 15 through 41. Additional descriptions of hydrologic functions and pollutant transport processes that operate within a watershed can be found in Appendix C.

WATERSHED ASSESSMENT AND MODELING

The AVGWLF model was run to establish existing loading conditions for the Conococheague Creek Watershed, and Subbasins 1 and 2 in the Pequea Creek Watershed. Adjustments to specific GWLF-related parameters were made based on information gathered from county conservation districts and field observations.

<u>Conococheague Adjustments</u>

- Reset “C” factor to 0.16 for Cropland land to account for use of continuous cover crop.
- Reset “P” factor to 0.30 for Hay/Pasture and Cropland land uses to account for use of riparian forest and grasses along streams, strip cropping, and buffer strips.

<u>Pequea Adjustments</u>

Subbasin 1

- Reset c for cropland to 0.21 to account for large farms with no crop rotation.

Subbasin 2

- Reset p for cropland and hay/pasture to 0.52 to account for lack of riparian buffers and significant stream bank erosion

The initial modeling run produced pollutant loads for the Pequea that were comparable to loads calculated from observed nutrient loads. Table 5 presents an explanation of the header information contained in Tables 6, 7, and 8. The 20-year means for these parameters for each impaired subbasin are shown in Tables 6 and 7. Table 8 shows the results for the reference watershed, Conococheague Creek.

Table 5. Header Information Contained in Tables 5 and 6

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

Table 6. Existing Loading Values for Subbasin 1 of Pequea Creek

Land Use	Area (acres)	Total P (lbs/yr)	Sediment Load (lbs/yr)
HAY/PAST	12238.34	7507.54	3760274.67
CROPLAND	16007.40	69722.68	38585544.12
CONIF_FOR	642.91	11.90	6370.41
MIXED_FOR	774.57	15.21	8201.11
DECID_FOR	5332.03	358.03	203220.38
TRANSITION	3.11	7.05	3691.16
DEVELOPED	1244.75	722.45	23085.25
GROUNDWATER	--	3254.27	--
POINT SOURCE	--	1211.00	--
TOTAL	36243.11	82810.15	42590387.10

Table 7. Existing Loading Values for Subbasin 2 of Pequea Creek.

Land Use	Area (acres)	Total P (lbs/yr)	Sediment Load (lbs/yr)
HAY/PAST	14614.58	9123.08	3706007.34
CROPLAND	16899.40	54283.20	31079847.84
CONIF_FOR	467.90	5.51	3000.90
MIXED_FOR	588.23	10.14	5648.19
DECID_FOR	8652.53	620.82	371819.20
QUARRY	19.35	38.36	23404.92
TRANSITION	8.45	12.35	5747.39
DEVELOPED	606.68	499.78	23090.31
GROUNDWATER	--	3092.83	--
POINT SOURCE	--	1349.30	--
TOTAL	41857.12	69004.05	35218566.09

Table 8. Existing Loading Values for Conococheague Creek			
Land Use	**Area (acres)**	**Total P (lbs/yr)**	**Sediment Load (lbs/yr)**
HAY/PAST	12404.42	1656.98	738175.04
CROPLAND	19511.02	8884.76	7057009.26
CONIF_FOR	323.70	1.76	866.41
MIXED_FOR	822.84	5.29	3009.94
DECID_FOR	2710.69	23.15	16203.59
TRANSITION	49.42	62.17	52160.84
DEVELOPED	3494.00	1919.32	21247.06
GROUNDWATER	--	2982.82	--
POINT SOURCE	--	22984.00	--
TOTAL	39316.09	38520.07	7888672.12

The unit area load for each pollutant in each watershed was estimated by dividing the mean annual loading (lbs/year) by the total area (acres). Results for the unit area loadings can be found in Table 9. Unit area loads for phosphorus and sediment in Subbasin 1 are 2.26 lbs/acre/yr and 1,175 lbs/acre/yr respectively. Unit area loads for phosphorus and sediment in Subbasin 2 are 1.64 lbs/acre/yr and 841 lbs/acre/yr respectively. Unit area loads for phosphorus and sediment in the Conococheague Creek Watershed are 0.98 lbs/acre/yr and 200 lbs/acre/yr respectively.

Table 9. Unit Area Loads for the Pequea and Conococheague Watersheds		
Watershed	**Unit area load for P (lbs/acre/yr)**	**Unit area load for Sediment (lbs/acre/yr)**
Subbasin 1	2.28	1,175
Subbasin 2	1.65	841
Conococheague Creek	0.98	200

TMDL COMPUTATIONS FOR PHOSPHORUS AND SEDIMENT

The TMDLs established for Pequea Creek consist of a load allocation (LA) and a margin of safety (MOS) for phosphorus and sediment. The wasteload allocation (WLA) accounts for point source discharges located within the watershed

TMDL Computation

The load reduction calculations in Pequea Creek are based on the current loading rates for phosphorus and sediment in the Conococheague Creek, the reference watershed. Based on biological assessment, Conococheague Creek is attaining its aquatic life uses. Conococheague Creek is designated as a *cold water fishery* (CWF). The nutrient and sediment unit area loading rates were computed for Conococheague Creek using the AVGWLF model (Table 9). These unit area loading rates were then used as the basis for establishing the TMDLs for Pequea Creek.

The TMDL value for each pollutant was determined by multiplying the unit area loading rates for Conococheague Creek by the total watershed area for Subbasins 1 and 2 of Pequea Creek. Table 10 presents this information. Tables 11 and 12 show allocations for each subbasin.

Table 10. TMDL Computation for Pequea Creek			
Pollutant	**Unit Area Loading Rate in Conococheague Creek (lbs/acre/yr)**	**Total Watershed Area (acres)**	**TMDL Value (lbs/yr)**
Subbasin 1			
Phosphorus	0.98	36,243.11	35,518
Sediment	200	36,243.11	7,248,622
Subbasin 2			
Phosphorus	0.98	41,857.12	41,020
Sediment	200	41,857.12	8,371,424

Table 11. TMDL Allocations for Subbasin 1							
Land Use	**Area (ac)**	**Phosphorus**			**Sediment**		
		Current Loads (lbs/yr)	**LA (lbs/yr)**	**% Reduction**	**Current Load (lbs/yr)**	**LA (lbs/yr)**	**% Reduction**
Hay/Past	12238.34	7507.54	3671.50	51	3760274.67	1149669.66	69
Cropland	16007.40	69722.68	21609.99	69	38585544.12	5138217.33	87
Conif_For	642.91	11.90	11.90	0	6370.41	6370.41	0
Mixed_For	774.57	15.21	15.21	0	8201.11	8201.11	0
Decid_For	5332.03	358.03	358.03	0	203220.38	203220.38	0
Transition	3.11	7.05	7.05	0	3691.16	3691.16	0
Developed	1244.75	722.45	546.25	24	23085.25	14389.75	38
Ground-water	--	3254.27	3254.27	0	--	--	--
Point Source	--	1211.00	3908.00	0	--	--	--
TOTAL	36243.11	82810.15	33382.20	60	42590387.10	6523759.8	85

Table 12. TMDL Allocations for Subbasin 2							
Land Use	Area (ac)	Phosphorus			Sediment		
		Current Loads (lbs/yr)	LA (lbs/yr)	% Reduction	Current Load (lbs/yr)	LA (lbs/yr)	% Reduction
Hay/Past	14614.58	9123.08	4969.0	45	3706007.34	1232739.8	67
Cropland	16899.40	54283.20	25349.1	53	31079847.84	5876766.4	81
Conif_For	467.90	5.51	5.51	0	3000.90	3000.90	0
Mixed_For	588.23	10.14	10.14	0	5648.19	5648.19	0
Decid_For	8652.53	620.82	620.82	0	371819.20	371819.20	0
Quarry	19.35	38.36	38.36	0	23404.92	23404.92	0
Transition	8.45	12.35	12.35	0	5747.39	5747.39	0
Developed	606.68	499.78	382.2	23	23090.31	15154.9	34
Ground-water	--	3061.52	3061.52	0	--	--	--
Point Source	--	1349.3	2939	0	--	--	--
TOTAL	41857.12	69004.05	37388	46	35218566.09	7534281.7	79

For the purpose of allocating loads in an impaired stream segment, the TMDL equation is as follows: TMDL = WLA + LA + MOS

The Point source contributions to the watershed for use in determining the loading rate in the reference watershed, and serving as the target-loading rate for the impaired watershed, were determined using the Discharge Monitoring Records (DMR) data for each facility. DMR data are also used in assessing the existing point source contributions to the impaired watershed. There is no in-stream module in the GWLF model; therefore, in-stream nutrient losses must be accounted for in order to accurately represent the load at the watershed outlet. The method used to estimate in-stream losses from point sources was taken from the USGS SPARROW (**SPA**tially **R**eferenced **R**egressions **o**n **W**atershed Attributes) model (Preston, 2000). SPARROW estimates in-stream nutrient losses using a decay function based on travel time and stream flow. Travel time to the watershed outlet is calculated for each facility using flow velocity, as determined by flow volume and a representative cross-sectional area of the stream based on field measurements at several sites along the reach, and distance traveled. A summary of point sources can be found in Table 13.

For computing the TMDL with respect to point-source discharges, the permit limit was used. The WLA (wasteload allocation) for the watershed is set to the sum of the permitted loads for each discharger in the watershed. In-stream losses are not applied to the permitted loads in setting the WLA. The WLA portion of this equation is the total loading that is assigned to point sources. The LA (load allocation) is the portion of this equation that is assigned to nonpoint sources. The MOS (margin of safety) is the portion of loading that is reserved to account for any uncertainty in the data and computational methodology used for the analysis, represented by 10% of the TMDL value. Table 14 presents the TMDLs for Pequea Creek.

Table 13. NPDES permits within the Pequea Creek Watershed					
Facility	**NPDES Permit**	**Flow (MGD)**		**Phosphorus (lbs/year)**	
		Permit Limit	Avg. from 1999 DMR	Permit Limit	Avg. from 1999 DMR
Suubasin 1					
Quarryville WWTP	0028886	0.400	0.250	1218	366
Calamus Estates	0082708	0.015	0.010	319	92
Paradise Twp WWTP	0083470	0.12	0.045	731	685
Hershey Farms	0080756	0.14	0.025	852	68
David Fite WWTP #1	0247898	0.0186	0	113	0
David Fite WWTP #2	pending	0.081	0	493	0
Pequea Septage	0084956	0.03	0	182	0
Subbasin 2					
Gap WWTP	0081574	0.580	0.090	1904	824
Rosehill WWTP	0084484	0.021	0.010	127	41.7
Crestwood Mobile Home Park	0080365 (cancelled)	0.043 connected to Gap	0.020	262 (transferred to Gap)	87.6
Pequea Valley Elem Sch	0038318	0.009	0.004	274	122
Pequea Valley High Sch	0038326	0.0208	0.009	633	274

Table 14. TMDLs for Pequea Creek				
Pollutant	**TMDL (lbs/yr)**	**WLA (lbs/yr)**	**LA (lbs/yr)**	**MOS (lbs/yr)**
Subbasin 1				
Phosphorus	35,518	3,908	29,474.2	2,135.8
Sediment	7,248,622	0	6,523,759.8	724,862.2
Subbasin 2				
Phosphorus	41,020	2,938	34,449.0	3,633
Sediment	8,371,424	0	7,534,281.6	837,142.4

The individual components of the TMDLs are discussed in detail below.

Margin of Safety

The Margin of Safety (MOS) for the original 2001 report was calculated as ten percent of the total TMDL for each parameter. Using ten percent of the TMDL load was based on professional judgement and provided an additional level of protection to the uses of the waterbody. The 2001 report was found to be in error by omitting several existing point sources. This revision of the 2001 report incorporates the omitted point sources by subtracting their associated loads from the original ten percent MOS reserve. The resulting reduced MOS is as follows:

Subbasin 1
Phosphorus – 2135.8 / 35,518 = 6.0 %
Sediment – 724,862.2 / 7,248,622 = 10 % (unchanged)

Subbasin 2
Phosphorus – 3633 / 41,020 = 8.9 %
Sediment - 837,142.4 / 8,371,424 = 10 % (unchanged)

Load Allocation

The load allocation (LA) for each subbasin was computed by subtracting the margin of safety value from the TMDL value. A waste load allocation (WLA) was also subtracted from the LA for Subbasin 1. Individual load allocations were then assigned to land uses/sources that are shown in Table 15. Not all land use/source categories were included in the allocation because they are difficult to control, or they provide an insignificant portion of the total load. Loading values for land uses/ sources that were not part of the allocation were carried through at their existing loading value.

Observations made in the field showed significant runoff originating from both agricultural land and residential/urban development. Since best management practices (BMPs) such as riparian buffers would not discriminate between reductions in either nutrients or sediment, land uses associated with these activities were included in the reduction scenario.

Phosphorus

1. The MOS and WLA were subtracted from the TMDL value.

   Subbasin 1
   LA = 35,518 (TMDL) – 2,135.8 (MOS) – 3,908 (WLA)
   LA = 29,474.2 lbs/yr

   Subbasin 2
   LA = 41,020 (TMDL) – 3,633 (MOS) – 2,938 (WLA)
   LA = 34,449 lbs/yr

2. Since the impairments are believed to be primarily caused by agricultural activities and runoff from developed areas, only the loads associated with these land uses (HAY/PAST, ROW_CROPS, and DEVELOPED) were considered in the reduction scenario. The remaining loads were subtracted from the LA value.

   Subbasin1
   Adjusted LA = 29,474.20 – 3646.46
   Adjusted LA = 25,827.74 lbs/yr

   Subbasin 2
   Adjusted LA = 34,449 – 3748.7
   Adjusted LA = 30,700.30 lbs/yr

This is the portion of the load that is available to allocate among the contributing sources. This is termed the allocable load.

3. It is important that the TMDL target load for each segment be achievable. For this reason, the subbasins were further divided into allocation units. Subbasins 1 and 2 have 11 and 13 allocation units respectively (Figures 2 and 3, Table 2). These allocation units provide a specific target load for tributaries within the unit boundaries. The unit area loading rates determined by the model were used to calculate the load allocations based on the land use distribution within each allocation unit. The following section shows the allocation process in detail.

4. Using the unit area loading rates determined by the model, the loads were allocated among the four remaining land uses: Hay/Past, Row Crops, and Developed. The allocation method used was Equal Marginal Percent Reduction (EMPR).

   EMPR is carried out in the following manner. Each land use/source load is compared with the allocable load to determine if any contributor would exceed the allocable load by itself. The evaluation is carried out as if each source is the only contributor to the pollutant load to the receiving waterbody. If the contributor exceeds the allocable load, that contributor is reduced to the allocable load. This is the baseline portion of EMPR. After any necessary reductions have been made in the baseline, the multiple analysis is run.

   The multiple analyses will sum all of the baseline loads and compare them to the allocable load. If the allocable load is exceeded, an equal percent reduction will be made to all contributors' baseline values. After any necessary reductions in the multiple analysis, the final reduction percentage for each contributor can be computed. A detailed description of the EMPR method can be found in Appendix D.

5. The results of the Load Allocations for Subbasins 1 and 2 are presented in Tables 15 and 16. The load allocation for each land use is shown along with the percent reduction necessary for each source. The impaired segment, as listed on Pennsylvania's 303(d) list, can be matched with the allocation unit using Table 2.

Table 15. Subbasin 1 Load Allocation for Phosphorus by Land Use/Source						
Land Use	**Acres**	**Current Loading Rate (lbs/acre/yr)**	**Allowable Loading Rate (lbs/acre/yr)**	**Current Load (lbs/yr)**	**Load Allocation (lbs/yr)**	**Percent Reduction**
Allocation Unit 1 – Big Beaver Creek / Pequea Creek						
Hay/Past	2542.36	0.61	0.30	1550.84	762.71	51
Row Crops	3600.94	4.36	1.35	15700.10	4861.27	69
Developed	124.32	0.58	0.44	72.11	54.70	24
Allocation Unit 2 – Big Beaver Creek / Unnamed Tributary						
Hay/Past	450.12	0.61	0.30	274.57	135.04	51
Row Crops	916.02	4.36	1.35	3993.85	1236.63	69
Developed	7.34	0.58	0.44	4.26	3.23	24
Allocation Unit 3 – South Fork Big Beaver Creek / Unnamed Tributary						
Hay/Past	1236.71	0.61	0.30	754.39	371.01	51
Row Crops	1865.85	4.36	1.35	8135.11	2518.90	69
Developed	347.15	0.58	0.44	201.35	152.75	24
Allocation Unit 4 – Big Beaver Creek						
Hay/Past	1214.47	0.61	0.30	740.83	364.34	51
Row Crops	1543.83	4.36	1.35	6731.10	2084.17	69
Developed	16.46	0.58	0.44	9.55	7.24	24
Allocation Unit 5 – Little Beaver Creek / Unnamed Tributary						
Hay/Past	1208.24	0.61	0.30	737.03	362.47	51
Row Crops	1366.14	4.36	1.35	5956.37	1844.29	69
Developed	33.81	0.58	0.44	19.61	14.88	24
Allocation Unit 6 – Little Beaver Creek / Unnamed Tributary						
Hay/Past	392.74	0.61	0.30	239.57	117.82	51
Row Crops	440.78	4.36	1.35	1921.80	595.05	69
Developed	0.00	--	--	--	--	--
Allocation Unit 7 – Calamus Run / Unnamed Tributary						
Hay/Past	780.37	0.61	0.30	476.03	234.11	51
Row Crops	864.21	4.36	1.35	3767.96	1166.68	69
Developed	18.35	0.58	0.44	10.64	8.07	24
Allocation Unit 8 – Pequea Creek / Unnamed Tributary						
Hay/Past	472.13	0.61	0.30	288.00	141.64	51
Row Crops	499.71	4.36	1.35	2178.74	674.61	69
Developed	27.14	0.58	0.44	15.74	11.94	24

Table 15. (Continued)

Land Use	Acres	Current Loading Rate (lbs/acre/yr)	Allowable Loading Rate (lbs/acre/yr)	Current Load (lbs/yr)	Load Allocation (lbs/yr)	Percent Reduction
Allocation Unit 9 – Pequea Creek / Unnamed Tributary						
Hay/Past	1663.48	0.61	0.30	1014.72	499.04	51
Row Crops	1703.06	4.36	1.35	7425.34	2299.13	69
Developed	302.63	0.58	0.44	175.53	133.16	24
Allocation Unit 10 – Pequea Creek / Unnamed Tributary						
Hay/Past	1576.08	0.61	0.30	961.41	472.82	51
Row Crops	2384.46	4.36	1.35	10396.25	3219.02	69
Developed	322.02	0.58	0.44	186.77	141.69	24
Allocation Unit 11 – Walnut Run						
Hay/Past	701.64	0.61	0.30	428.00	210.49	51
Row Crops	822.40	4.36	1.35	3585.66	1110.24	69
Developed	42.26	0.58	0.44	24.51	18.59	24

Table 16. Subbasin 2 Load Allocation for Phosphorus by Land Use/Source						
Land Use	**Acres**	**Current Loading Rate (lbs/acre/yr)**	**Allowable Loading Rate (lbs/acre/yr)**	**Current Load (lbs/yr)**	**Load Allocation (lbs/yr)**	**Percent Reduction**
Allocation Unit 1 – Eshelman Run						
Hay/Past	949.16	0.62	0.34	588.5	322.7	45
Row Crops	1142.64	3.21	1.5	3667.9	1714.0	53
Developed	97.41	0.82	0.63	79.9	61.4	23
Allocation Unit 2 – Londonland Run						
Hay/Past	1223.15	0.62	0.34	758.4	415.9	45
Row Crops	1514.69	3.21	1.5	4862.2	2272.0	53
Developed	91.62	0.82	0.63	75.1	57.7	23
Allocation Unit 3 – Houston Run						
Hay/Past	910.24	0.62	0.34	564.3	309.5	45
Row Crops	1001.87	3.21	1.5	3216.0	1502.8	53
Developed	10.23	0.82	0.63	8.4	6.4	23
Allocation Unit 4 – Pequea Creek / Unnamed Tributary						
Hay/Past	1012.54	0.62	0.34	627.8	344.3	45
Row Crops	942.04	3.21	1.5	3023.9	1413.1	53
Developed	139.88	0.82	0.63	114.7	88.1	23
Allocation Unit 5 – Unnamed Tributary						
Hay/Past	568.65	0.62	0.34	352.6	193.3	45
Row Crops	558.86	3.21	1.5	1793.9	838.3	53
Developed	25.35	0.82	0.63	20.8	16.0	23
Allocation Unit 6 – Indian Spring Run						
Hay/Past	668.28	0.62	0.34	414.3	227.2	45
Row Crops	1141.75	3.21	1.5	3665.0	1712.6	53
Developed	2.00	0.82	0.63	1.6	1.3	23
Allocation Unit 7 – Pequea Creek / Unnamed Tributary						
Hay/Past	2439.4	0.62	0.34	1512.4	829.4	45
Row Crops	3204.42	3.21	1.5	10286.2	4806.6	53
Developed	10.9	0.82	0.63	8.9	6.9	23
Allocation Unit 8 – Pequea Creek / Unnamed Tributary						
Hay/Past	1265.62	0.62	0.34	784.7	430.3	45
Row Crops	1294.98	3.21	1.5	4156.9	1942.5	53
Developed	15.79	0.82	0.63	12.9	9.9	23

Table 16. (Continued)

Land Use	Acres	Current Loading Rate (lbs/acre/yr)	Allowable Loading Rate (lbs/acre/yr)	Current Load (lbs/yr)	Load Allocation (lbs/yr)	Percent Reduction
Allocation Unit 9 – Richardson Run / Unnamed Tributary						
Hay/Past	1047.46	0.62	0.34	649.4	356.1	45
Row Crops	1143.98	3.21	1.5	3672.2	1716.0	53
Developed	7.12	0.82	0.63	5.8	4.5	23
Allocation Unit 10 – Umbles Run / Unnamed Tributary / Richardson Run						
Hay/Past	969.62	0.62	0.34	601.2	329.7	45
Row Crops	1029.44	3.21	1.5	3304.5	1544.2	53
Developed	34.69	0.82	0.63	28.4	21.9	23
Allocation Unit 11 – Pequea Creek / Unnamed Tributary						
Hay/Past	596.89	0.62	0.34	370.1	202.9	45
Row Crops	861.54	3.21	1.5	2765.5	1292.3	53
Developed	9.34	0.82	0.63	7.7	5.9	23
Allocation Unit 12 – Walnut Run / Unnamed Tributary						
Hay/Past	844.64	0.62	0.34	523.7	287.2	45
Row Crops	863.09	3.21	1.5	2770.5	1294.6	53
Developed	38.7	0.82	0.63	31.7	24.4	23
Allocation Unit 13 – Pequea Creek						
Hay/Past	2118.93	0.62	0.34	1313.7	720.4	45
Row Crops	2200.1	3.21	1.5	7062.3	3300.2	53
Developed	123.65	0.82	0.63	101.4	77.9	23

Sediment

1. The margin of safety value was subtracted from the TMDL value. This quantity represents the load allocation (LA).

   Subbasin 1
   LA = 7,248,622 – 724,862.2 lbs/year
   LA = 6,523,759.8 lbs/year

   Subbasin 2
   LA = 8,371,424 – 837,142.4 lbs/year
   LA = 7,534,281.6 lbs/year

2. Again, only loads associated with agricultural activities or nonpoint urban runoff were considered in the reduction scenario. The remaining loads were subtracted from the LA value.

Subbasin 1
Adjusted LA = 6,523,759.8 – 221,483.06
Adjusted LA = 6,302,276.74 lbs/year

Subbasin 2
Adjusted LA = 7,534,281.6 – 409,620.60
Adjusted LA = 7,124,661.0 lbs/year

This is the portion of the load that is available to allocate among contributing sources. This is termed the allocable load.

3. This quantity was allocated among the four remaining land use/sources. The allocation method used was Equal Marginal Percent Reduction (EMPR). The allocation method is discussed above in the phosphorus section.

4. The results of the load allocations for both Subbasins 1 and 2 are presented in Tables 19 and 20. The load allocation for each land use is shown along with the percent reduction necessary for each source. The impaired segment, as listed on Pennsylvania's 303(d) list, can be matched with the allocation unit using Table 2.

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Table 19. Subbasin 1 Load Allocation for Sediment by Land Use/Source						
Land Use	**Acres**	**Current Loading Rate (lbs/acre/yr)**	**Allowable Loading Rate (lbs/acre/yr)**	**Current Load (lbs/yr)**	**Load Allocation (lbs/yr)**	**Percent Reduction**
Allocation Unit 1 – Big Beaver Creek / Pequea Creek						
Hay/Past	2542.36	307.25	93.94	781140.11	238829.30	69
Row Crops	3600.94	2410.48	320.99	8679993.85	1155865.73	87
Developed	124.32	18.55	11.59	2306.14	1440.87	38
Allocation Unit 2 – Big Beaver Creek / Unnamed Tributary						
Hay/Past	450.12	307.25	93.94	138299.37	42284.27	69
Row Crops	916.02	2410.48	320.99	2208047.89	294033.26	87
Developed	7.34	18.55	11.59	136.16	85.07	38
Allocation Unit 3 – South Fork Big Beaver Creek / Unnamed Tributary						
Hay/Past	1236.71	307.25	93.94	379979.15	116176.54	69
Row Crops	1865.85	2410.48	320.99	4497594.11	598919.19	87
Developed	347.15	18.55	11.59	6439.63	4023.47	38
Allocation Unit 4 – Big Beaver Creek						
Hay/Past	1214.47	307.25	93.94	373145.91	114087.31	69
Row Crops	1543.83	2410.48	320.99	3721371.34	495553.99	87
Developed	16.46	18.55	11.59	305.33	190.77	38
Allocation Unit 5 – Little Beaver Creek / Unnamed Tributary						
Hay/Past	1208.24	307.25	93.94	371231.74	113502.07	69
Row Crops	1366.14	2410.48	320.99	3293053.15	438517.28	87
Developed	33.81	18.55	11.59	627.18	391.86	38
Allocation Unit 6 – Little Beaver Creek / Unnamed Tributary						
Hay/Past	392.74	307.25	93.94	120669.37	36894.00	69
Row Crops	440.78	2410.48	320.99	1062491.37	141485.97	87
Developed	0.00	--	--	--	--	--
Allocation Unit 7 – Calamus Run / Unnamed Tributary						
Hay/Past	780.37	307.25	93.94	239768.68	73307.96	69
Row Crops	864.21	2410.48	320.99	2083160.92	277402.77	87
Developed	18.35	18.55	11.59	340.39	212.68	38

Table 19. (Continued)

Land Use	Acres	Current Loading Rate (lbs/acre/yr)	Allowable Loading Rate (lbs/acre/yr)	Current Load (lbs/yr)	Load Allocation (lbs/yr)	Percent Reduction
Allocation Unit 8 – Pequea Creek / Unnamed Tributary						
Hay/Past	472.13	307.25	93.94	145061.94	44351.89	69
Row Crops	499.71	2410.48	320.99	1204540.96	160401.91	87
Developed	27.14	18.55	11.59	503.45	314.55	38
Allocation Unit 9 – Pequea Creek / Unnamed Tributary						
Hay/Past	1663.48	307.25	93.94	511104.23	156267.31	69
Row Crops	1703.06	2410.48	320.99	4105192.07	546665.23	87
Developed	302.63	18.55	11.59	5613.79	3507.48	38
Allocation Unit 10 – Pequea Creek / Unnamed Tributary						
Hay/Past	1576.08	307.25	93.94	484250.58	148056.96	69
Row Crops	2384.46	2410.48	320.99	5747693.14	765387.82	87
Developed	322.02	18.55	11.59	5973.47	3732.21	38
Allocation Unit 11 – Walnut Run						
Hay/Past	701.64	307.25	93.94	215578.89	65912.06	69
Row Crops	822.40	2410.48	320.99	1982378.75	263982.18	87
Developed	42.26	18.55	11.59	783.92	489.79	38

Table 20. Subbasin 2 Load Allocation for Sediment by Land Use/Source.						
Land Use	**Acres**	**Current Loading Rate (lbs/acre/yr)**	**Allowable Loading Rate (lbs/acre/yr)**	**Current Load (lbs/yr)**	**Load Allocation (lbs/yr)**	**Percent Reduction**
Allocation Unit 1 – Eshelman Run						
Hay/Past	949.16	253.58	84.35	240688.0	80061.6	67
Row Crops	1142.64	1839.11	347.75	2101440.7	397353.1	81
Developed	97.41	38.06	24.98	3707.4	2433.3	34
Allocation Unit 2 – Londonland Run						
Hay/Past	1223.15	253.58	84.35	310166.4	103172.7	67
Row Crops	1514.69	1839.11	347.75	2785681.5	526733.4	81
Developed	91.62	38.06	24.98	3487.1	2288.7	34
Allocation Unit 3 – Houston Run						
Hay/Past	910.24	253.58	84.35	230818.7	76778.7	67
Row Crops	1001.87	1839.11	347.75	1842549.1	348400.3	81
Developed	10.23	38.06	24.98	389.4	255.5	34
Allocation Unit 4 – Pequea Creek / Unnamed Tributary						
Hay/Past	1012.54	253.58	84.35	256759.9	85407.7	67
Row Crops	942.04	1839.11	347.75	1732515.2	327594.4	81
Developed	139.88	38.06	24.98	5323.8	3494.2	34
Allocation Unit 5 – Unnamed Tributary						
Hay/Past	568.65	253.58	84.35	144198.3	47965.6	67
Row Crops	558.86	1839.11	347.75	1027805.0	194343.6	81
Developed	25.35	38.06	24.98	964.8	633.2	34
Allocation Unit 6 – Indian Spring Run						
Hay/Past	668.28	253.58	84.35	169462.4	56369.4	67
Row Crops	1141.75	1839.11	347.75	2099803.8	397043.6	81
Developed	2	38.06	24.98	76.1	50.0	34
Allocation Unit 7 – Pequea Creek / Unnamed Tributary						
Hay/Past	2439.4	253.58	84.35	618583.1	205763.4	67
Row Crops	3204.42	1839.11	347.75	5893280.9	1114337.1	81
Developed	10.9	38.06	24.98	414.9	272.3	34
Allocation Unit 8 – Pequea Creek / Unnamed Tributary						
Hay/Past	1265.62	253.58	84.35	320935.9	106755.0	67
Row Crops	1294.98	1839.11	347.75	2381610.7	450329.3	81
Developed	15.79	38.06	24.98	601.0	394.4	34

Table 20. (Continued)

Land Use	Acres	Current Loading Rate (lbs/acre/yr)	Allowable Loading Rate (lbs/acre/yr)	Current Load (lbs/yr)	Load Allocation (lbs/yr)	Percent Reduction
Allocation Unit 9 – Richardson Run / Unnamed Tributary						
Hay/Past	1047.46	253.58	84.35	265614.9	88353.3	67
Row Crops	1143.98	1839.11	347.75	2103905.1	397819.0	81
Developed	7.12	38.06	24.98	271.0	177.9	34
Allocation Unit 10 – Umbles Run / Unnamed Tributary / Richardson Run						
Hay/Past	969.62	253.58	84.35	245876.2	81787.4	67
Row Crops	1029.44	1839.11	347.75	1893253.4	357987.8	81
Developed	34.69	38.06	24.98	1320.3	866.6	34
Allocation Unit 11 – Pequea Creek / Unnamed Tributary						
Hay/Past	596.89	253.58	84.35	151359.4	50347.7	67
Row Crops	861.54	1839.11	347.75	1584466.8	299600.5	81
Developed	9.34	38.06	24.98	355.5	233.3	34
Allocation Unit 12 – Walnut Run / Unnamed Tributary						
Hay/Past	844.64	253.58	84.35	214183.8	71245.4	67
Row Crops	863.09	1839.11	347.75	1587317.4	300139.5	81
Developed	38.7	38.06	24.98	1472.9	966.7	34
Allocation Unit 13 – Pequea Creek						
Hay/Past	2118.93	253.58	84.35	537318.3	178731.7	67
Row Crops	2200.10	1839.11	347.75	4046225.9	765084.8	81
Developed	123.65	38.06	24.98	4706.1	3088.8	34

Consideration of Critical Conditions

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

CONSIDERATION OF SEASONAL VARIATIONS

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

REASONABLE ASSURANCE OF IMPLEMENTATION

The pollutant reductions in the TMDLs are allocated to agricultural and residential/urban development activities in the watershed. Implementation of best management practices (BMPs) in the affected areas should achieve the loading reduction goals established in the TMDLs. Substantial reductions in the amount of sediment reaching the streams can be made through the planting of riparian buffer zones, contour strips, and cover crops. These BMPs range in efficiency from 20% to 70% for sediment reduction. Implementation of BMPs aimed at sediment reduction will also assist in the reduction of phosphorus. Additional phosphorus reductions can be achieved through the installation of more effective animal waste management systems and stone ford cattle crossings. Other possibilities for attaining the desired reductions in phosphorus and sediment include streambank stabilization and fencing. Further ground truthing will be performed in order to assess both the extent of existing BMPs, and to determine the most cost-effective and environmentally protective combination of BMPs required to meet the nutrient and sediment reductions outlined in this report.

Remediation Plan

Collaborative efforts between several state, federal, and local agencies have identified segments for implementation of BMPs (Green and Passmore, 1999). Proposed remediation efforts include streambank fencing, bank stabilization, stone ford cattle crossings, and fish enhancement structures.

ASSESSMENT OF MEASURES AND FOLLOW-UP MONITORING

Streambank fencing has been installed along the reaches of several small tributaries to Pequea Creek. These tributaries include Eshelman Run, Londonland Run, Richardson Run, and Umbles Run. Eshelman Run represents the tributary. This work has been conducted by local citizens with assistance and guidance from the Lancaster County Conservation District and the Natural Resource Conservation Service. However, the reduction in nutrient and sediment loads to the stream has not been assessed following installment of the fences.

The Pequea/Mill Creek National Monitoring project, sponsored by the U.S. Geological Survey (USGS), has been studying the effectiveness of various BMPs on the improvement of surface and ground water quality. However, most of the work and research has focused on Mill Creek, a tributary to the Conestoga River. Future efforts associated with this program hope to focus on tributaries to Pequea Creek (WRAS, 1999).

PUBLIC PARTICIPATION

Notice of the draft TMDLs will be published in the *PA Bulletin* and local newspapers with a 60-day comment period provided. A public meeting with watershed residents will be held to discuss the TMDLs. Notice of final TMDL approval will be posted on the Pa. DEP website.

LITERATURE CITED

Green, J., and M. Passmore, 1999. The Biological Condition of Streams in the Pequea and Mill Creek Watersheds in Pennsylvania. U.S. EPA Internal Report, Region III Biology Group, 14 pp.

Haith, D.A., and L.L. Shoemaker, 1987. Generalized Watershed Loading Functions for Stream Flow Nutrients. Water Resources Bulletin, 23(3), pp. 471-478.

McMorran, C. P., 1986. Water Quality and Biological Survey of the Lower Susquehanna Subbasin. Susquehanna River Basin Commission Pub. No. 104, 114 pp.

Nizeyimana, E., B.M. Evans, M.C. Anderson, G.W. Petersen, D.R. DeWalle, W.E. Sharpe, J.M. Hamlett and B.R. Swistock, 1997. Quantification of NPS Pollution Loads within Pennsylvania. Environmental Resources Research Institute, The Pennsylvania State University, Pub. No. ER97-08, 61 pp.

Novotny, V., and H. Olem, 1994. Water Quality: Prevention, Identification, and Management of Diffuse Pollution. Van Nostrand Reinhold, New York.

Preston, S., 2000. Personal communication.

Samuels, W., 1998. Case Studies: Solving Watershed-Based Problems Through the Use of GIS, Internet and EPA National Data Bases. In: Watershed Management: Moving from Theory to Implementation, Water Environment Federation, Denver, Colorado, pp. 1175-1182.

Thomann, R.V., and J.A. Mueller, 1987. Principles of Surface Water Quality Modeling and Control. Harper & Row, New York.

Watershed Restoration Action Strategy (WRAS) for Subbasin 07K, 1999. Pennsylvania Department of Environmental Protection, Bureau of Watershed Conservation, 15 p.