Total Maximum Daily Load (TMDL) For Nutrients and Sediments in the Donegal Creek

Lancaster County

Pennsylvania Department of Environmental Protection
Office of Water Management, Bureau of Watershed Conservation
April 11, 2000

Information Sheet
TMDL For Donegal Creek Watershed

What is being proposed?
A Total Maximum Daily Load or TMDL plan has been developed to improve the water quality in the Donegal Creek Watershed.

Who is proposing the plan? To whom? Why?
The Pennsylvania Department of Environmental Protection (DEP) is proposing to submit the plan to the US Environmental Protection Agency (EPA) for review and approval as required by the federal regulation.

In 1995, EPA was sued for not developing TMDLs when Pennsylvania did not do so. DEP has entered into an agreement with EPA to develop TMDLs for certain waters over the next several years. DEP developed this TMDL in compliance with the state/EPA agreement.

What is a TMDL?
A Total Maximum Daily Load (TMDL) sets a ceiling on the pollutant loads that can enter a waterbody so that the waterbody will meet water quality standards. The Clean Water Act requires states to list all waters that do not meet their water quality standards even after pollution controls required by law are in place. For these waters, the state must calculate how much of a substance can be put in the water without violating the standard, and then distribute that quantity to all the sources of the pollutant on that waterbody. A TMDL plan includes waste load allocations for point sources, load allocations for nonpoint sources and a margin of safety.

The Clean Water Act requires states to submit TMDLs to EPA for approval. Also, if a state does not develop the TMDL, the Clean Water Act states that EPA must do so.

What is a water quality standard?
The Clean Water Act sets a national minimum goal that all waters be "fishable" and "swimmable." To support this goal, states must adopt water quality standards.

Water quality standards are state regulations which have two components. The first component is a use, such as warm water fishes or recreation. States determine the uses supported by each of their waters. The second component relates to the instream conditions necessary to protect the uses. These conditions or criteria are physical, chemical or biological characteristics, such as temperature, the minimum concentration of dissolved oxygen, and the maximum concentrations of toxic pollutants.

It is the combination of "uses" and "criteria" that make up water quality standards. If criteria are being exceeded, the uses are not being met, and the water is said to be violating water quality standards.

What is the purpose of the plan?
The Donegal Creek watershed was determined to be impaired from excess nutrient and sediment contributions. This determination was made based on the health of the biological community

residing in the water. The plan includes a calculation of the loading for both the nutrient and sediment that will meet the water quality objectives.

Why was the Donegal Creek watershed selected for a TMDL?

In 1996, DEP listed stream segments in the Donegal Creek watershed under Section 303(d) of the federal Clean Water Act as impaired due to excess nutrient and sediment loading. The watershed was reassessed in 1997 using the rapid bioassessment method, and the 1998 Section 303(d) listing reflects the results of that reassessment. The following tables show the 303(d) listings for the Donegal Creek watershed.

Pennsylvania's 1996 Section 303(d) List includes the following entry for Donegal Creek:

Segment ID	Stream Code	Stream	Source Code	Cause Code	Miles Degraded
7036	07920	Donegal Creek	Agriculture	Suspended Solids	1.5
				Organic enrichments/DO	0.5
				Nutrients	2.1
6424	07920	UNT Donegal Creek	Agriculture	Suspended Solids	1.7
				Organic Enrichments	0.4
				Nutrients	0.1

The 1998 Section 303(d) List for Donegal Creek is as follows:

Segment ID	Stream Code	Stream Name	Source	Cause	Miles
7036	07920	Donegal Creek	Agriculture	Siltation	2.53
			Agriculture	Organic Enrichments/Low DO	
			Agriculture	Nutrients	7.14

The 1998 listing does not add any new stream segments to the 1996 list. The TMDL applies to all listed segments from both the 1996 and 1998 lists..

What pollutants does this TMDL address?

The proposed plan provides calculations of the stream's total capacity to accept phosphorus and sediments. Based on evaluation of the concentrations of nutrients in Donegal Creek, it has been determined that phosphorus is the cause of the nutrient impairment to the stream segments.

Where do the pollutants come from?

All of the pollution in the Donegal Creek watershed comes from non-point sources (NPS) of pollution. The pollutants come primarily from overland runnoff.

How was the TMDL developed?

DEP used a reference watershed approach to estimate the necessary loading reduction of phosphorus and sediment that would be needed to restore a healthy aquatic community and allow the streams in the watershed to achieve their designated uses. The reference watershed approach is based on selecting a non-impaired watershed that has similar land use characteristics and determining the current loading rates for the pollutants of interest. This is done by modeling the loads that enter the stream, using precipitation and land use characteristic data. For this analysis we used the AVGWLF model (the Environmental Resources Research Institute of the Pennsylvania State University's ArcView based version of the Generalized Watershed Loading Function model developed by Cornell University). This modeling process uses loading rates in the non-impaired watershed as a target for loading reductions in the impaired watershed. The impaired watershed is modeled to determine the current loading rates and determine what reductions are necessary to meet the loading rates of the non-impaired watershed.

The reference stream approach was used to set allowable loading rates in the affected watersheds because neither Pennsylvanian nor EPA has water quality criteria for phosphorus or sediment.

How much pollution is too much?
The allowable amount of pollution in a waterbody varies depending on several conditions. TMDLs are set to meet water quality standards at the critical flow condition. For a free flowing stream impacted by non-point source pollution loading from nutrients and sediment, the TMDL is expressed as a yearly loading. This accounts for pollution contributions over all stream flow conditions.

DEP has established the water quality objectives for phosphorus and sediment by using the reference watershed approach. This approach assumes that when the impared watershed achieves loadings similar to the unimpaired, reference watershed, the impairment is eliminated. Reducing the current loading rates for phosphorus and sediment in the impaired watershed to the current loading rates in the reference watershed will result in meeting the water quality objectives.

How will the loading limits be met?
BMP's (Best Management Practices) will be installed throughout the watershed to achieve the necessary loading reductions.

How can I get more information on the TMDL?
To request a copy of the full report, contact Lee A. McDonnell at 717-787-9637 or by writing to him at Pennsylvania Department of Environmental Protection, Bureau of Watershed Conservation, 400 Market St., Harrisburg PA 17105 or e-mail at mcdonnell.lee@dep.state.pa.us.

How can I comment on the proposal?
You may provide e-mail or written comments postmarked no later than January 20, 1999 to the above address.

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TMDLs for Donegal Creek Watershed

Executive Summary

The Donegal Creek watershed in Lancaster County is 17.2 square miles. The protected uses of the watershed are water supply, recreation and aquatic life. The aquatic use for the main stem Donegal Creek is trout stocking fishes, for the unnamed tributaries is cold water fishes, and for Donegal Springs is high quality cold water fishes.

Total Maximum Daily Loads or TMDLs were developed for the Donegal Creek watershed to address the impairments noted on Pennsylvania's 1996 and 1998 Clean Water Act Section 303(d) Lists. The impairments were found during biological surveys of the aquatic life in the stream. The impairments are caused by excess nutrient and sediment loads from agriculture. The nutrient portion of the TMDL focuses on control of phosphorus. Phosphorus is generally held to be the limiting nutrient in a waterbody when the nitrogen/phosphorus ratio exceeds 10 to 1; in Donegal Creek the ratio is 37 to1.

Pennsylvania does not currently have water quality criteria for sediment or phosphorus. For this reason, we developed a reference watershed approach to identify the TMDL endpoints or water quality objectives for phosphorus and sediment in the impaired segments of the Donegal Creek watershed. By comparison to a similar non-impaired watershed, Pennsylvania estimated that the amount of phosphorus loading that will meet the water quality objectives for Donegal Creek is 3,287 pounds per year. Sediment loading must be limited to 792,998 pounds per year. When these values are met, Donegal Creek will support its aquatic life uses.

The TMDLs for Donegal Creek are allocated as shown in the table below.

TMDL for Donegal Creek

Pollutant	TMDL (lb/yr)	LA (lb/yr)	WLA (lb/yr)	MOS (lb/yr)
Phosphorus	3,287	2,958	0	329
Sediment	792,998	713,698	0	79,300

The TMDLs are allocated to the agricultural non-point sources (Load Allocations - LAs) with 10% of the allowable loading reserved as a margin of safety (MOS). There are no wasteload allocations (WLA) for point sources because there are no known point source discharges in the impaired areas of the watershed. The TMDLs cover a total of 9.67 miles of the main stem Donegal Creek and an Unnamed Tributary. The TMDL establishes a reduction for phosphorus loading of 50% from the current yearly loading of 5,924 pounds, and a reduction in sediment loading of 61% from the current yearly loading of 1,813,165 pounds.

A more complete discussion of the Donegal Creek TMDLs 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 Donegal Creek watershed to address the impairments noted on Pennsylvania's 1996 and 1998 Clean Water Act Section 303(d) Lists.

It was first determined that Donegal Creek was not meeting its designated water quality uses for protection of aquatic life based on a 1994 aquatic biological survey, which included kick screen analysis and habitat surveys. In 1997, the Department again surveyed the stream and found the stream to still be impaired. As a consequence of the surveys, Pennsylvania listed Donegal Creek and an unnamed tributary on the 1996 and 1998 Section 303(d) Lists of Impaired Waters. The 1998 list did not add any new segments to the 1996 list although the affected miles increased. The stream was listed because of impacts by sediments, nutrients, organic enrichment, and low dissolved oxygen from agriculture. Pennsylvania is using a method to develop TMDLs based on comparing the impacted watershed to a reference watershed to determine the appropriate watershed loading for nutrients and sediments. Based on the predominance of agricultural land use in the watershed, nutrients and sediments are the most likely pollutants causing Donegal Creek to violate the aquatic life use. Therefore, the TMDLs proposes reducing the phosphorus and sediment loadings in Donegal Creek watershed to levels consistent with Brubaker Run watershed, the reference watershed. Because of the similarities in landuse between the two watersheds, achieving phosphorus and sediment loadings in the Donegal Creek TMDL will ensure that the aquatic life use is achieved and maintained as evidenced in Brubaker Run.

Table 1. 1996 Section 303(d) Listing forDonegal Creek Watershed

Segment ID	Stream Code	Stream	Source Code	Cause Code	Miles Degraded
7036	07920	Donegal Creek	Agriculture	Suspended Solids	1.5
				Organic enrichments/DO	0.5
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Table 2. 1998 Section 303(d) Listing forDonegal Creek Watershed

Segment ID	Stream Code	Stream Name	Source	Cause	Miles
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			Agriculture	Nutrients	7.14

The primary method that the Department has adopted for evaluating the waters of the Commonwealth changed between the publication of the 1996 and 1998 303(d) lists. The Department is now using a modification of EPA's 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 stream that can be assessed per site varies. There are several factors that determine site location and how long a "single site" assessed segment can be. Some of these factors are distinct changes in stream characteristics, surface geology, riparian land use, point-source and nonpoint-source discharge locations, and the pollutant that is causing impairment.

For the purpose of TMDL development it is often necessary to aggregate 303(d) listed stream segments together. The primary reason to address multiple segments is compatibility with data used in TMDL analysis, as in impairment caused by excess nutrient and sediment. 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 100 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 the two segments listed in the Donegal Creek watershed. This results in completing TMDLs for both segments, although the analysis was completed as one watershed area.

Neither Pennsylvania nor EPA currently has water quality criteria for sediment or nutrients. It is for this reason, we developed a reference watershed approach to identify the TMDL endpoints or water quality objectives for nutrients and sediment in the impaired segments of the Donegal Creek watershed. The nutrient portion of the TMDL for this watershed only addresses phosphorus because it was determined that phosphorus was the limiting nutrient in the stream. Phosphorus is generally held to be the limiting nutrient in a waterbody when the nitrogen/phosphorus ratio exceed 10 to 1, the ratio in Donegal Creek is 37 to1.

Reference Watershed Approach

Since PA has no instream criteria for the pollutants of concern we adopted a reference watershed approach to set allowable loading rates in the affected watersheds. The reference watershed approach is used to estimate the necessary loading reduction of phosphorus and sediment that would be needed to restore a healthy aquatic community and allow the streams in the watershed to achieve their designated uses. The reference watershed approach is based on selecting a non-impaired watershed that has similar land use characteristics and determining the current loading rates for the pollutants of interest. This is done by modeling the loads that enter the stream, using precipitation and land use characteristic data. For this analysis we used the AVGWLF model (the Environmental Resources Research Institute of the Pennsylvania State University's ArcView based version of the Generalized Watershed Loading Function model developed by Cornell University). This modeling process uses loading rates in the non-impaired watershed as a target for loading reductions in the impaired watershed. The impaired watershed is modeled to determine the current loading rates and determine what reductions are necessary to meet the loading rates of the non-impaired watershed.

GWLF models surface runoff using the Soil Conservation Service Curve Number (SCS-CN) approach with daily weather (temperature and precipitation) inputs. All of the equations used by the model can be viewed in Attachment E, GWLF Users Manuel.

The Donegal 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?). Attachments C and D provide information on the method being used by Pennsylvania for establishment of TMDLs for stream segments impaired by nutrients and sediment and, watershed hydrology and pollutant transport.

Watershed History

The Donegal Creek watershed in Lancaster County is 17.2 square miles in the Ridge and Valley Physiographic Province. The protected uses of the watershed are water supply, recreation and aquatic life. As listed in 25 PA Code Chapter 93 , Section 93.9o, the designated aquatic life use for the main stem Donegal Creek is trout stocking fishes and the Unnamed Tributary is cold water fishes.

In June 1992, the Pennsylvania Fish and Boat Commission published the results of a study of the East Branch of the Donegal Creek, finding the stream to be moderately degraded and nutrient enriched.

In 1994, the Department conducted an aquatic biological survey on Donegal Creek to collect background information on the macroinvertebrate community and to determine the water quality of the stream. Results clearly identified Donegal Creek was degraded due to extensive agricultural activities in the watershed, primarily from lack of riparian vegetation in pastures where cattle have complete access to the stream, causing severe stream bank erosion. Department biologists concluded in the 1994 aquatic investigation report that water quality will remain poor until buffer zones are established to protect the streams.

The primary land use (92%) in the Donegal Creek watershed is agriculture, with areas adjacent to the stream used for row crops and pasture. Cattle generally have free access to the stream. The majority of the stream, during the 1994 survey, had no protected riparian zone. Proper management practices are being conducted along the unimpaired stream segments. These unimpaired areas contribute an insignificant amount of loading to the overall watershed.

The 1997 survey showed that sedimentation was still a problem. Sediment deposited in large quantities on the stream bed degrades the habitat of bottom-dwelling macroinvertebrates. It was also documented that nutrients from agricultural activities were causing increased algal growths.

TMDL Endpoints

The TMDLs address sediment and phosphorus, which was determined to be the limiting nutrient for plant growth in Donegal Creek. Because neither Pennsylvania nor EPA has water quality criteria for phosphorus or sediment, we had to develop a method to determine water quality objectives for these parameters that would result in the impaired stream segments attaining their designated uses. The method employed for these TMDLs is termed the "Reference Watershed Approach".

The Reference Watershed Approach pairs 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 rate of nutrients and sediment in the impaired stream segment to a level equivalent to or slightly lower than the loading rate in the non-impaired, reference stream segment. This load reduction will allow the biological community to return to the impaired stream segments.

The TMDL endpoints established for this analysis were determined using Brubaker Run as the reference watershed. These endpoints are discussed in detail in the TMDL section.

The biological assessment used EPA waterbody cause code 1200, Organic Enrichment/Low Dissolved Oxygen (D.O.), to describe the impairment seen in this portion of Donegal Creek. The listing was based on visual observation. There were no dissolved oxygen readings used as the basis for this impairment listing. The listing for impairment caused by organic enrichment/ low dissolved oxygen is addressed through reduction to the phosphorus load. A detailed explanation of this process is included in the following section.

Relationship Between Dissolved Oxygen Levels, Nutrient Loads and Organic Enrichment in Stream Systems

As indicated earlier, Donegal Creek was 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) 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. For this reason, the ratio of the amount of N to the amount of P is often used to make this determination (Thomann and Mueller, 1987). If the N/P ratio is less than 10, nitrogen is limiting; if the N/P ratio is greater than 10, phosphorus is the limiting nutrient. In the case of Donegal Creek, the N/P ratio is approximately 37, which points to phosphorus as the limiting nutrient. Controlling the phosphorus loading to Donegal Creek will limit plant growth and result in raising the dissolved oxygen level.

Selection of the Reference Watershed

Two factors formed the basis to select a suitable reference watershed. The first factor was to use a watershed that had been assessed by the Department using the Unassessed Waters Protocol and had been determined to attain water quality standards. The second factor was to find a watershed that closely resembled the Donegal watershed in physical properties such as land cover/landuse, physiographic province, size, and geology. This was done by means of a desktop screening using several GIS coverages. Map 3 shows the land use characterization for both watersheds. Chart 1 contained in Attachment B presents a bar graph of land use characteristics in each watershed.

The GIS coverages included the USGS named stream watershed coverage, the state water plan boundaries, the satellite image derived land cover grid (MRLC), streams and Pennsylvania's 305(b) assessed streams database.

The first step in determining the reference watershed was to locate a watershed that had been recently assessed and was not impaired. Several watersheds were discovered this way. Step two involved comparing the landcover data coverage by watershed and selecting unimpaired watersheds that looked similar to the Donegal watershed. This step narrowed the selected watersheds to five. The remaining watersheds were analyzed by value counts for each pixel of the GIS coverage to determine landcover types by percentage. Brubaker was the only watershed with all characteristics needed to represent the Donegal as a reference watershed.

The geologies of the Donegal and Brubaker watersheds were then compared, but this did not produce a very good match. The Donegal watershed consists of carbonates and interbedded shales and carbonates, and the Brubaker watershed consists primarily of clastics. The model, however, compensates for the disparity in the geology of the two watersheds with data that equates the differences. The bedrock geology influences soil type as well as fractures and directional permeability. The Statsco soil coverage is used to model characteristics of the material derived from the bedrock. The Soilphos coverage provides soil sample data used to set phosphorus and sediment values for the universal soil loss equation (USLE). Well data is used to calculate levels of nitrogen in groundwater to account for the difference of flow in the different rock types.

Data Compilation and Model Overview

The TMDLs were developed using the Generalized Watershed Loading Function or GWLF model. The GWLF model provides the ability to simulate runoff, sediment, and nutrient (N and P) loadings from 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 Attachment E, GWLF Users Manuel.

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, 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 Attachment B). 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 3 lists the GIS data sets and provides explanation of how they were used for development of the input files for the GWLF model.

State-Wide GIS Data Sets

The following GIS data sets were used during the modeling process using AVGWLF:

Table 3 GIS Data Sets

Censustr	Coverage of Census data including information on individual homes septic systems. The attribute *susew_sept* includes data on conventional systems, and *su_other* provides data on short circuiting and other systems.
County	The County boundaries coverage lists data on conservation practices which provides C and P values 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 *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 has been generated from soil sample data. Used to help set phosphorus and sediment values.
Smallsheds	A coverage of watersheds at the 1:24,000 scale set a name stream level???. This coverage is used with the stream network to delineate the desired level watershed.
Statsco	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 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 *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 non-point 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 non-point 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 amounts 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, this factor is largely controlled by the crops grown and the cultivation practices utilized. 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 F 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 D.

As described in the next section, the GIS interface was first used to derive values for the various GWLF input parameters. Based on subsequent field work in the two watersheds, various parameter values were then adjusted to more accurately reflect local conditions.

Watershed Assessment and Modeling

The AVGWLF model was run in both the Donegal Creek Watershed and the Brubaker Run Watershed to establish existing loading conditions. The initial modeling run produced pollutant loads for the Donegal and Brubaker watersheds that were similar to the results of a study (Quantification of NPS Pollution Loads Within Pennsylvania Watersheds), which estimated loads based on land cover, animal density, population and other landuse activities. This was expected since both watersheds had similar activities and the default values for soil loss and transport to streams were identical. To model nutrient production and transport to streams, a survey of both watersheds was conducted to determine actual land use patterns and management practices. To determine loadings in the Donegal watershed prior to recent improvements, historic records as well as onsite observations were used.

These observations were used to adjust modeling parameters to more accurately reflect conditions in Donegal Creek and Brubaker Run with respect to cropping patterns, conservation practices, animal populations/manure loads, and background N in groundwater.

General observations of watershed characteristics:

Donegal: less topographic relief, more continuous corn crops, more animals (particularly poultry operations), dominated by limestone/dolomite geology (more conducive to N leaching), less evidence of conservation practices.

Brubaker: more topographic relief, more corn-hay rotations, more crop residue left, more use of strip cropping and stream buffers, fewer animals (approximately half the density of Donegal), dominated by shale and metamorphic rock (less conducive to N leaching).

Adjustments to specific GWLF-related parameters:

Donegal:
- re-set "C" factor to 0.38 to account for continuous corn crops
- re-set "P" factor to 0.8 to reflect general lack of conservation practices
- re-set N concentration in runoff over agricultural land to 5.8 mg/l (default is 2.9)
- re-set P concentration in runoff over agricultural land to 0.51 mg/l (default is 0.26)
- re-set N concentration in runoff during manure-spreading periods to 24.4 mg/l (default is 12.2)
- re-set P concentration in runoff during manure-spreading periods to 3.8 mg/l (default is 1.9)
- re-set background concentration of N in groundwater to 10 mg/l to reflect conditions typical of limestone in south-central PA
- re-set background concentration of P in groundwater to 0.020 mg/l to reflect conditions typical of limestone in south-central PA
- re-set background concentration of P in soil to 2100 mg/kg

Brubaker:
- re-set "C" factor to 0.14 to account for corn-hay rotations
- re-set "P" factor to 0.64 to account for use of strip cropping and buffer strips
- re-set N concentration in runoff over agricultural land to 4.4 mg/l (default is 2.9)
- re-set P concentration in runoff over agricultural land to 0.39 mg/l (default is 0.26)
- re-set N concentration in runoff during manure-spreading periods to 18.3 mg/l (default is 12.2)
- re-set P concentration in runoff during manure-spreading periods to 2.9 mg/l (default is 1.9)
- re-set background concentration of N in groundwater to 5 mg/l to reflect conditions typical of shale/metamorphic rock in south-central PA
- re-set background concentration of P in groundwater to 0.02 mg/l to reflect conditions typical of shale/metamorphic rock in south-central PA
- re-set background concentration of P in soil to 1950 mg/kg

Using the above settings, sediment and nutrient loads were estimated with GWLF for the Donegal and Brubaker watersheds. This established the existing conditions for each watershed. The 4-year means for these parameters for each watershed are shown Tables 5 and 6. 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) resulting in an approximate loading per unit area for the watershed. Table 4 presents an explanation of the header information contained in Tables 5 and 6.

Table 4. Header information for Tables 5 and 6.

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

Table 5. Existing Loading Values for Donegal Creek

Land Use Category	Area (acres)	Total P (lbs/yr)	Unit Area P Load (lbs/acre/yr)	Total N (lbs/yr)	Unit Area N Load (lbs/acre/yr)	Sed Load (lbs/year)	Unit Area Sed Load (lbs/acre/yr)
Hay/Past	2538	265	0.10	2933	1.16	34874	13.74
Row Crops	521	353	0.68	1499	2.88	122455	234.87
Prob Row C	7032	4807	0.68	20154	2.87	1651693	234.87
Coniferous	27	0	0.00	0	0.00	374	13.74
Mixed For	59	0	0.00	0	0.00	815	13.74
Deciduous	215	0	0.00	22	0.10	2954	13.74
Lo Int Dev	351	22	0.06	110	0.31	0	0.00
Hi Int Dev	190	154	0.81	1323	6.95	0	0.00
Quarry	22	0	0.00	22	0.99	0	0.00
Groundwater		331		164736			
Point Source		0		0			
Septic Systems		22		6483			
Total	10956	5954	0.54	197281	18.01	1813165	165.49

Table 6. Existing Loading Values for Brubaker Run

Land Use Category	Area (acres)	Total P (lbs/yr)	Unit Area P Load (lbs/acre/yr)	Total N (lbs/yr)	Unit Area N Load (lbs/acre/yr)	Sed Load (lbs/year)	Unit Area Sed Load (lbs/acre/yr)
Hay/Past	1495	132	0.09	1,345	0.90	26,414	17.67
Row Crops	398	154	0.39	794	2.00	42,175	106.01
Prob Row C	2923	1,103	0.38	5,843	2.00	309,892	106.01
Coniferous	47	0	0.00	0	0.00	830	17.67
Mixed For	74	0	0.00	0	0.00	1,310	17.67
Deciduous	403	22	0.05	44	0.11	7,116	17.67
Lo Int Dev	12	0	0.00	0	0.00	0	0.00
Hi Int Dev	5	0	0.00	44	8.92	0	0.00
Groundwater		198		48,444		0	
Point Source		0		0			
Septic Systems		22		4,212			
Total	5357	1,632	0.30	60,726	11.34	387,736	72.38

TMDL Computations for Phosphorus and Sediment

The TMDLs established for Donegal Creek consist of a load allocation (LA) and a margin of safety (MOS) for both phosphorus and sediment. There is no wasteload allocation (WLA) for this TMDL because there are no known point source discharges.

Nitrogen was not included in the TMDL because it was determined that the stream was phosphorus limited. If the ratio of nitrogen to phosphorus is greater than 10 to 1 it means that phosphorus will be the limiting nutrient in the stream. In the case of Donegal Creek the nitrogen to phosphorus ratio is 60,726 pounds of nitrogen to 1,632 pounds of phosphorus, or 37 to 1.

The basis for the load reduction calculations in Donegal Creek are based on the current loading rates for phosphorus and sediment in Brubaker Run, the reference watershed for this analysis. Based on biological assessment, it was determined that Brubaker Run was attaining its Aquatic life uses. Brubaker Run is designated as a cold water fishery (CWF). The phosphorus and sediment loading rates were computed for Brubaker Run using the AVGWLF model. These loading rates were then used as the basis for establishing the TMDLs for Donegal Creek.

The TMDL equation is as follows: TMDL = WLA + LA + MOS

The WLA (wasteload allocation) 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 non-point sources. The MOS (margin of safety) is the portion of loading that is reserved to account for any uncertainty in the data and computational methodology used for the analysis. Table 7 presents the TMDLs for Donegal Creek.

Table 7. TMDLs for Donegal Creek

Pollutant	TMDL (lb/yr)	LA (lb/yr)	WLA (lb/yr)	MOS (lb/yr)
Phosphorus	3,287	2,958	0	329
Sediment	792,998	713,698	0	79,300

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

TMDL Computation

The TMDL for both pollutants of concern was computed in the same manner. Each pollutants unit loading rate in Brubaker Run was multiplied by the total watershed area of Donegal Creek to give the TMDL value. Table 8 presents this information.

Table 8. TMDL Computation

Pollutant	Unit Area Loading Rate in Brubaker Run (lbs/acre/year)	Total Watershed Area in Donegal Creek (acres)	TMDL Value (lbs/year)
Phosphorus	0.30	10956	3,287
Sediment	72.38	10956	792,998

Margin of Safety

The Margin of Safety (MOS) for this analysis is explicit. Ten percent of each of the TMDLs was reserved as the MOS. Using ten percent of the TMDL load is based on professional judgement and will provide an additional level of protection to the uses of the waterbody.

Phosphorus – 3,287 x 0.1 = 329 lbs/year
Sediment - 792,998 x 0.1 = 79,300 lbs/year

Load Allocation

The load allocation (LA) for the entire watershed was computed by subtracting the margin of safety value from the TMDL value. Individual load allocations were then assigned to each land uses/ sources that are shown in Table 9. Not all land use/ source categories were included in the allocation because they are difficult to control, or provide an insignificant portion of the total load. Loading values for land uses/ sources that were not part of the allocation were carried through at their existing loading value. The following section shows the allocation process in detail.

Phosphorus

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

   LA = 3,287 – 329
   LA = 2958 lbs/year

2. The loads not considered in the reduction scenario were subtracted from the LA value. These are the loads: Lo Int Dev (Low Intensity Development), Hi Int Dev (High Intensity Development), Groundwater, Septic systems. The total load for these land uses/sources is 529 lbs. This quantity was subtracted from the LA.

   Adjusted LA = 2958 – 529
   Adjusted LA = 2429 lbs.year

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

3. This quantity was allocated among the three remaining land use/sources. The allocation method used was Equal Marginal Percent Reduction (EMPR).

   EMPR is carried out in the following manner. Each land use/source load will be 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 would be 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 analysis 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.

4. The results of the Load Allocation are presented in Table 9. The LA for each land use is shown along with the reduction necessary for each source.

Sediment

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

   LA = 792,998 – 79,300 lbs/year
   LA = 713,698 lbs/year

2. The loads not considered in the reduction scenario were subtracted from the LA value. These are the loads: Coniferous Forest, Mixed Forest, Deciduous Forest. The total load for these land uses/sources is 4143 lbs. This quantity was subtracted from the LA.

   Adjusted LA = 713,698 - 4143
   Adjusted LA = 709,555 lbs.year

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

3. This quantity was allocated among the three 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 Allocation are presented in Table 9. The LA for each land use is shown along with the reduction necessary for each source.

Table 9. Load Allocation by Land Use/ Source

		Phosphorus				**Sediment**			
Source		Unit Area Loading Rate	Annual average load	LA (annual average)	% Reduction	Unit Area Loading Rate	Annual average load	LA (annual average)	% Reduction
	acres	lbs/acre/ year	lbs/year	lbs/year		lbs/acre/ year	lbs/year	lbs/year	
Hay/Past	2538	0.10	265	211	20%	13.74	34,874	28,545	18%
Row Crops	521	0.68	353	281	20%	234.87	122,455	100,231	18%
Prob Row C	7032	0.68	4,807	1937	60%	234.87	1,651,693	580,780	65%
Coniferous	27	0.00	0	0	0%	13.74	374	374	
Mixed For	59	0.00	0	0	0%	13.74	815	815	
Deciduous	215	0.00	0	0	0%	13.74	2,954	2,954	
Lo Int Dev	351	0.06	22	22	0%				
Hi Int Dev	190	0.81	154	154	0%				
Quarry	22	0.00	0	0	0%				
Groundwater			331	331	0%				
Point Source			0	0	0%				
Septic Systems			22	22	0%				
Total	**10,956**	**0.54**	**5,954**	**2958**	**50%**	**165.49**	**1,813,165**	**713,698**	**61%**

Consideration of Critical Conditions

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

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 entirely to agricultural activities in the watershed. Implementation of best management practices (BMPs) in the affected areas should achieve the loading reduction goals established in the TMDLs. Remediation activities in the watershed have already begun. The primary remediation activities for the watershed are stream bank stabilization and fencing. Stabilizing the stream bank will reduce instream erosion. Fencing keeps livestock out of the stream and provides a riparian zone along the stream that traps sediment and phosphorus, keeping these pollutants from reaching the stream. Improvements have already been seen in the streamside habitat and aquatic biologic community following the implementation of these agricultural best management practices (BMPs) along affected streams. The following section presents loading reduction calculations projected for the watershed based on the BMPs that have been installed.

Projected Loading Reductions based on BMP Implementation

It is anticipated that sediment and nutrient loading along the stream will be reduced by 75% where BMPs have been installed. The 75% reduction in loading from BMP implementation is derived from empirical data from previous studies of BMP effectiveness and is described below. Map 1 of Attatchment B shows the location of BMPs recently installed along impaired stream segments.

The average annual phosphorus loads calculated in each case were 5,954 lbs/year for Donegal and 1,632 lb/yr for Brubaker. The loading rates for Donegal and Brubaker Run were estimated to be 0.54 lb/ac/yr and 0.30 lb/ac/yr, respectively. Both of these rates are below the unit area loads reported by Nizeyimana and Evans (1997), but are believed to be more realistic estimates of the loads in these areas since these calculations reflect actual conditions more accurately than the larger scale report.

The average annual sediment loads calculated in each case were 907 tons /yr for Donegal and 194 tons/yr for Brubaker. These values are far less than those derived earlier by DEP using a soil loss rate of 4 tons/acre as reported in the Soil Survey Report for Lancaster County. We have found that it is erroneous to use the soil loss rates reported in soil surveys since such soil loss rates account for both soil erosion and deposition. The GWLF modeled load is much more accurate since is represents only that amount actually delivered to surface water. Attachment A contains the modeling output for both watersheds

BMPs discussed below are described in the context of reducing sediment and phosphorus loads in Donegal Creek. The reduction of sediment loads is also expected to reduce phosphorus loads since much of the phosphorus that reaches a stream is attached to sediment particles, particularly in agricultural areas.

Streambank stabilization and fencing will be used to reduce phosphorus and sediment loads in the affected areas. A reduction coefficient of 75% for nutrients and sediment is reasonable to expect with this particular BMP. This level of reduction has been reported by Qiu and Prato (1998) and the Illinois EPA (1986), and is also used by the Susquehanna River Basin Commission in their efforts to model pollutant reductions that may result from various BMP reduction strategies (SRBC, 1996).

Load calculations for Donegal Creek after BMP implementation were compared to the reference watershed Brubaker Run in two ways to determine the effectiveness of the BMPs.

The first comparison applied the 75% reduction (allowing a loading of 25% of current load) to the entire watershed. The resulting loadings after BMP implementation are as follows:

Phosphorus

Loading after BMP implementation in all impaired segments:
0.25 (0.54 lb/ac/yr) = 0.14 lb/ac/yr

Sediment

Loading after BMP implementation in all impaired segments:
0.25 (165.5 lb/ac/yr) = 41.4 lb/ac/yr

The second comparison calculated reductions only for that portion of the Donegal watershed draining into impaired streams. As shown in Map 2, approximately 2/3 or 66% of the watershed drains into impaired streams. Therefore, the unit area loads for each pollutant were reduced by 75% for 2/3 of the watershed. This estimate is conservative because it does not reduce the loading in unimpaired areas and in areas where BMPS have already been installed. The new "weighted" unit area loads for the entire watershed were re-computed as follows:

Phosphorus

Loading after BMP implementation in impaired areas only:
0.25 (0.39 lb/ac/yr) = 0.10 lb/ac/yr
Weighted avg. load: 0.66 (0.10 lb/ac/yr) + 0.34 (0.39 lb/ac/yr) = 0.27 lb/ac/yr

Sediment

Loading after BMP implementation in impaired areas only:
0.25 (165.5 lb/ac/yr) = 41.4 lb/ac/yr
Weighted avg. load: 0.66 (41.4 lb/ac/yr) + 0.34 (165.5 lb/ac/yr) = 83.6 lb/ac/yr

Table 10. Loading Projection for Donegal Creek Based on BMP Implementation

	Phosphorus	Sediment
	lbs/ac/yr	lbs/ac/yr
Donegal – before BMPs	0.54	165.5
Donegal – after BMPs	0.14-0.27	41.4-83.6
Brubaker (reference)	0.30	72.3

Remediation Plan

An extensive watershed restoration effort is currently underway. In April 1995, the Lancaster County Conservation District and the Donegal Fish and Conservation Association entered into an MOU to promote and implement the Donegal Creek Restoration Project. The conservation district agreed to administer grant funds, oversee and design cattle crossings, oversee installation of riprap and fish enhancement structures and provide technical assistance to landowners for the design and installation of best management practices. The Donegal Fish and Conservation Association currently works with cooperating landowners and help install and maintain improvements.

The Donegal Creek Restoration Project received $110,557 funding from Section 319 FY 96 Grant. The project involves the following agencies:

Pennsylvania Fish and Boat Commission
Chesapeake Bay foundation
Alliance for the Chesapeake Bay
Pennsylvania association of Conservation Districts
Pennsylvania department of Conservation and Natural Resources
Donegal Fish and Conservation Association
Lancaster County conservation District

The Donegal Creek Restoration project includes the following activities to reduce sediment and phosphorus loadings to the stream and restore designated uses:

Best Management Practices	Pollutant Reduction
1. 4.9 miles of streambank fencing	75%
2. 6.67 miles of stream stabilization measures; bioengineering methods/riprap	75%
3. 21 stone ford cattle crossings with fencing	
4. 200 fish enhancement structures	

Assessment of Measures and Follow-up Monitoring

Installation of recommended practices is already underway. Water quality and habitat monitoring are being done by the Donegal Fish and Conservation Association at eight different stations in the watershed. Monitoring began prior to the installation of BMPs and includes biota, water chemistry and bank stability. The DEP will make the final determination regarding the stream's recovery. Although stream quality has shown steady improvement, it has not yet fully recovered from the impairments. The 1998 list designated more impaired stream than the 1996 303(d) list, reflecting a more accurate means of reporting water quality status. The Department has completed a stream GIS coverage at the 1:24,000 scale. In addition, the use of dynamic segmentation to accurately delineate the impaired segments has resulted in adding minor streams that had not been previously reported.

Recent surveys conducted by DEP biologists have documented an approximate 90% reduction of silt in some areas. Riparian zones have stabilized and narrowed stream channels. Several stations in the watershed were described as being capable of supporting a reproducing trout population. Follow-up surveys will continue to be conducted to document stream conditions.

A publication entitled "Fixing a Broken Trout Stream, the Donegal Creek Restoration Project" has been published and is available from the Lancaster County Conservation District.

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 Department website.

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Attachment A

Model Output

Donegal (10/18) 4 -year means

	PRECIP	EVAPOTRANS	GR.WAT.FLOW	RUNOFF	STREAMFLOW
	(cm)				
APR	5.9	2.3	3.8	0.2	4.0
MAY	6.3	6.7	1.2	0.0	1.2
JUN	4.5	9.4	0.5	0.0	0.5
JUL	6.8	10.7	0.0	0.0	0.1
AUG	5.3	8.1	0.0	0.0	0.0
SEP	7.2	4.6	0.0	0.0	0.0
OCT	4.6	1.8	0.0	0.0	0.0
NOV	4.8	1.0	0.0	0.1	0.1
DEC	6.7	0.4	1.4	1.1	2.5
JAN	4.7	0.2	2.2	0.6	2.7
FEB	4.0	0.4	2.5	0.7	3.2
MAR	9.0	1.0	5.3	1.1	6.4
ANNUAL	69.7	46.6	16.8	3.8	20.7

	EROSION	SEDIMENT	DIS.NITR	TOT.NITR	DIS.PHOS	TOT.PHOS
	(1000 Mg)		(Mg)			
APR	0.8	0.0	17.9	18.0	0.1	0.1
MAY	1.0	0.0	5.6	5.7	0.0	0.0
JUN	0.6	0.0	2.2	2.2	0.0	0.0
JUL	1.0	0.0	0.2	0.3	0.0	0.0
AUG	0.8	0.0	0.0	0.0	0.0	0.0
SEP	0.4	0.0	0.0	0.1	0.0	0.0
OCT	0.3	0.0	0.1	0.1	0.0	0.0
NOV	0.3	0.0	0.3	0.3	0.0	0.1
DEC	0.2	0.3	8.8	9.8	0.2	0.9
JAN	0.1	0.1	11.2	11.6	0.1	0.3
FEB	0.1	0.2	12.9	13.5	0.2	0.5
MAR	0.4	0.2	27.0	27.9	0.3	0.8
ANNUAL	5.9	0.8	86.3	89.5	0.9	2.7

SOURCE	AREA (ha)	RUNOFF (cm)	EROSION (Mg/ha)	DIS.NITR	TOT.NITR	DIS.PHOS	TOT.PHOS
				(Mg)			
HAY/PAST	1027.	2.15	0.11	1.28	1.33	0.09	0.12
ROW CROPS	211.	4.18	1.88	0.51	0.68	0.04	0.16
PROB ROW C	2846.	4.18	1.88	6.90	9.14	0.61	2.18
CONIFEROUS	11.	1.76	0.11	0.00	0.00	0.00	0.00
MIXED FOR	24.	1.76	0.11	0.00	0.00	0.00	0.00
DECIDUOUS	87.	1.76	0.11	0.00	0.01	0.00	0.00
LO INT DEV	142.	4.59	0.00	0.00	0.05	0.00	0.01
HI INT DEV	77.	14.01	0.00	0.00	0.60	0.00	0.07
QUARRY	9.	8.44	0.00	0.00	0.01	0:00	0.00
GROUNDWATER				74.71	74.71	0.15	0.15
POINT SOURCE				0.00	0.00	0.00	0.00
SEPTIC SYSTEMS				2.94	2.94	0.01	0.01
TOTAL				86.34	89.46	0.90	2.70

NUTRIENT DATA (Donegal Creek)

RURAL LAND USE	DIS.NITR IN RUNOFF(mg/l)	DIS.PHOS IN RUNOFF(mg/l)
HAY/PAST	5.8	.4
ROW CROPS	5.8	.51
PROB ROW C	5.8	.51
CONIFEROUS	.19	.006
MIXED FOR	.19	.006
DECIDUOUS	.19	.006

NUTRIENT CONCENTRATIONS IN RUNOFF FROM MANURED AREAS

LAND USE	NITROGEN(mg/l)	PHOSPHORUS(mg/l)
HAY/PAST	24.4	3.8
ROW CROPS	24.4	3.8
PROB ROW C	24.4	3.8

URBAN LAND USE	NITR.BUILD-UP(kg/ha-day)	PHOS.BUILD-UP(kg/ha-day)
LO INT DEV	.012	.0016
HI INT DEV	.101	.0112
QUARRY	.012	.0019

MONTH	POINT SOURCE NITR.(kg)	POINT SOURCE PHOS.(kg)
APR	0	0
MAY	0	0
JUN	0	0
JUL	0	0
AUG	0	0
SEP	0	0
OCT	0	0
NOV	0	0
DEC	0	0
JAN	0	0
FEB	0	0
MAR	0	0

NITROGEN IN GROUNDWATER (mg/l):	10.000
PHOSPHORUS IN GROUNDWATER (mg/l):	0.020
NITROGEN IN SEDIMENT (mg/kg):	3000
PHOSPHORUS IN SEDIMENT (mg/kg):	2100

MANURE SPREADING FEB THRU MAY

SEPTIC SYSTEMS

	POPULATION SERVED			
MONTH	NORMAL SYSTEMS	PONDING SYSTEMS	SHORT-CIRCUIT SYSTEMS	DISCHARGE SYSTEMS
APR	693	0	17	0
MAY	693	0	17	0
JUN	693	0	17	0
JUL	693	0	17	0
AUG	693	0	17	0
SEP	693	0	17	0
OCT	693	0	17	0
NOV	693	0	17	0
DEC	693	0	17	0
JAN	693	0	17	0
FEB	693	0	17	0
MAR	693	0	17	0

PER CAPITA TANK EFFLUENT NITROGEN (g/day) = 12
PER CAPITA TANK EFFLUENT PHOSPHORUS (g/day) = 2.5
PER CAPITA GROWING SEASON NITROGEN UPTAKE (g/day) = 1.6
PER CAPITA GROWING SEASON PHOSPHORUS UPTAKE (g/day) = .4

```
TRANSPRT DATA (Donegal Creek)

LAND USE       AREA(ha)       CURVE NO       KLSCP
HAY/PAST         1027.          75.0          0.00100
ROW CROPS         211.          82.0          0.01700
PROB ROW C       2846.          82.0          0.01700
CONIFEROUS         11.          73.0          0.00100
MIXED FOR          24.          73.0          0.00100
DECIDUOUS          87.          73.0          0.00100
LO INT DEV        142.          83.0          0.00100
HI INT DEV         77.          93.0          0.00100
QUARRY              9.          89.0          0.01900

MONTH     ET CV()    DAY HRS    GROW. SEASON    EROS. COEF
APR        0.480       13         0              .3
MAY        0.840       14         1              .3
JUN        0.840       15         1              .3
JUL        0.840       15         1              .3
AUG        0.840       14         1              .3
SEP        0.840       12         1              .12
OCT        0.480       11         0              .12
NOV        0.480       10         0              .12
DEC        0.480       9          0              .12
JAN        0.480       9          0              .12
FEB        0.480       10         0              .12
MAR        0.480       12         0              .12

ANTECEDENT RAIN+MELT FOR DAY -1 TO DAY -5
 0         0         0         0         0
INITIAL UNSATURATED STORAGE (cm)  =   10
INITIAL SATURATED STORAGE (cm)    =   0
RECESSION COEFFICIENT (1/day)     =   .1
SEEPAGE COEFFICIENT (1/day)       =   0
INITIAL SNOW (cm water)           =   0
SEDIMENT DELIVERY RATIO           =  0.140
UNSAT AVAIL WATER CAPACITY (cm)   =   17
```

```
Brubaker (10/18)     4 -year means

         PRECIP        EVAPOTRANS   GR.WAT.FLOW  RUNOFF        STREAMFLOW
            ----------------(cm)---------------------------------

APR       5.9            2.4            3.9          0.1           4.0
MAY       6.3            7.0            1.9          0.0           1.9
JUN       4.5            9.4            0.8          0.0           0.8
JUL       6.8            9.3            0.1          0.0           0.1
AUG       5.3            6.8            0.0          0.0           0.0
SEP       7.2            4.7            0.0          0.0           0.0
OCT       4.6            1.9            0.0          0.0           0.0
NOV       4.8            1.1            0.1          0.1           0.2
DEC       6.7            0.4            2.2          1.0           3.2
JAN       4.7            0.2            2.3          0.5           2.8
FEB       4.0            0.4            2.8          0.6           3.4
MAR       9.0            1.1            6.3          1.0           7.2
-------------------------------------------------------------------
ANNUAL   69.7           44.9           20.3          3.4          23.7

         EROSION   SEDIMENT   DIS.NITR   TOT.NITR   DIS.PHOS   TOT.PHOS
          ----(1000 Mg)----           ------------(Mg)-----------------

APR        0.1        0.0        4.7        4.7        0.0        0.0
MAY        0.2        0.0        2.2        2.2        0.0        0.0
JUN        0.1        0.0        0.9        0.9        0.0        0.0
JUL        0.2        0.0        0.1        0.1        0.0        0.0
AUG        0.1        0.0        0.0        0.0        0.0        0.0
SEP        0.1        0.0        0.0        0.0        0.0        0.0
OCT        0.0        0.0        0.0        0.0        0.0        0.0
NOV        0.0        0.0        0.3        0.3        0.0        0.0
DEC        0.0        0.1        3.5        3.7        0.1        0.2
JAN        0.0        0.0        3.1        3.2        0.1        0.1
FEB        0.0        0.0        3.8        3.9        0.1        0.1
MAR        0.1        0.1        8.3        8.5        0.1        0.2
---------------------------------------------------------------------
ANNUAL     1.0        0.2       26.9       27.5        0.4        0.7

SOURCE         AREA    RUNOFF   EROSION   DIS.NITR TOT.NITR DIS.PHOS TOT.PHOS
               (ha)    (cm)     (Mg/ha)     ---------------(Mg)------------
HAY/PAST        605.     2.15      0.11       0.57     0.61     0.04     0.06
ROW CROPS       161.     4.18      0.66       0.30     0.36     0.03     0.07
PROB ROW C     1183.     4.18      0.66       2.17     2.65     0.19     0.50
CONIFEROUS       19.     1.76      0.11       0.00     0.00     0.00     0.00
MIXED FOR        30.     1.76      0.11       0.00     0.00     0.00     0.00
DECIDUOUS       163.     1.76      0.11       0.01     0.02     0.00     0.01
LO INT DEV        5.     4.59      0.00       0.00     0.00     0.00     0.00
HI INT DEV        2.    14.01      0.00       0.00     0.02     0.00     0.00
GROUNDWATER                                  21.97    21.97     0.09     0.09
POINT SOURCE                                  0.00     0.00     0.00     0.00
SEPTIC SYSTEMS                                1.91     1.91     0.01     0.01
-----------------------------------------------------------------------------
TOTAL                                        26.93    27.54     0.36     0.74
```

NUTRIENT DATA (Brubaker Run)

RURAL LAND USE	DIS.NITR IN RUNOFF(mg/l)	DIS.PHOS IN RUNOFF(mg/l)
HAY/PAST	4.4	.29
ROW CROPS	4.4	.39
PROB ROW C	4.4	.39
CONIFEROUS	.19	.006
MIXED FOR	.19	.006
DECIDUOUS	.19	.006

NUTRIENT CONCENTRATIONS IN RUNOFF FROM MANURED AREAS

LAND USE	NITROGEN(mg/l)	PHOSPHORUS(mg/l)
HAY/PAST	18.3	2.9
ROW CROPS	18.3	2.9
PROB ROW C	18.3	2.9

URBAN LAND USE	NITR.BUILD-UP(kg/ha-day)	PHOS.BUILD-UP(kg/ha-day)
LO INT DEV	.012	.0016
HI INT DEV	.101	.0112

MONTH	POINT SOURCE NITR.(kg)	POINT SOURCE PHOS.(kg)
APR	0	0
MAY	0	0
JUN	0	0
JUL	0	0
AUG	0	0
SEP	0	0
OCT	0	0
NOV	0	0
DEC	0	0
JAN	0	0
FEB	0	0
MAR	0	0

NITROGEN IN GROUNDWATER (mg/l): 5.000
PHOSPHORUS IN GROUNDWATER (mg/l): 0.020
NITROGEN IN SEDIMENT (mg/kg): 3000
PHOSPHORUS IN SEDIMENT (mg/kg): 1950

MANURE SPREADING FEB THRU MAY

SEPTIC SYSTEMS

	POPULATION SERVED			
MONTH	NORMAL SYSTEMS	PONDING SYSTEMS	SHORT-CIRCUIT SYSTEMS	DISCHARGE SYSTEMS
APR	450	0	12	0
MAY	450	0	12	0
JUN	450	0	12	0
JUL	450	0	12	0
AUG	450	0	12	0
SEP	450	0	12	0
OCT	450	0	12	0
NOV	450	0	12	0
DEC	450	0	12	0
JAN	450	0	12	0
FEB	450	0	12	0
MAR	450	0	12	0

PER CAPITA TANK EFFLUENT NITROGEN (g/day) = 12
PER CAPITA TANK EFFLUENT PHOSPHORUS (g/day) = 2.5
PER CAPITA GROWING SEASON NITROGEN UPTAKE (g/day) = 1.6
PER CAPITA GROWING SEASON PHOSPHORUS UPTAKE (g/day) = .4

TRANSPRT DATA (Brubaker Run)

LAND USE	AREA(ha)	CURVE NO	KLSCP
HAY/PAST	605.	75.0	0.00100
ROW CROPS	161.	82.0	0.00600
PROB ROW C	1183.	82.0	0.00600
CONIFEROUS	19.	73.0	0.00100
MIXED FOR	30.	73.0	0.00100
DECIDUOUS	163.	73.0	0.00100
LO INT DEV	5.	83.0	0.00100
HI INT DEV	2.	93.0	0.00100

MONTH	ET CV()	DAY HRS	GROW. SEASON	EROS. COEF
APR	0.510	13	0	.3
MAY	0.880	14	1	.3
JUN	0.880	15	1	.3
JUL	0.880	15	1	.3
AUG	0.880	14	1	.3
SEP	0.880	12	1	.12
OCT	0.510	11	0	.12
NOV	0.510	10	0	.12
DEC	0.510	9	0	.12
JAN	0.510	9	0	.12
FEB	0.510	10	0	.12
MAR	0.510	12	0	.12

ANTECEDENT RAIN+MELT FOR DAY -1 TO DAY -5

0	0	0	0	0

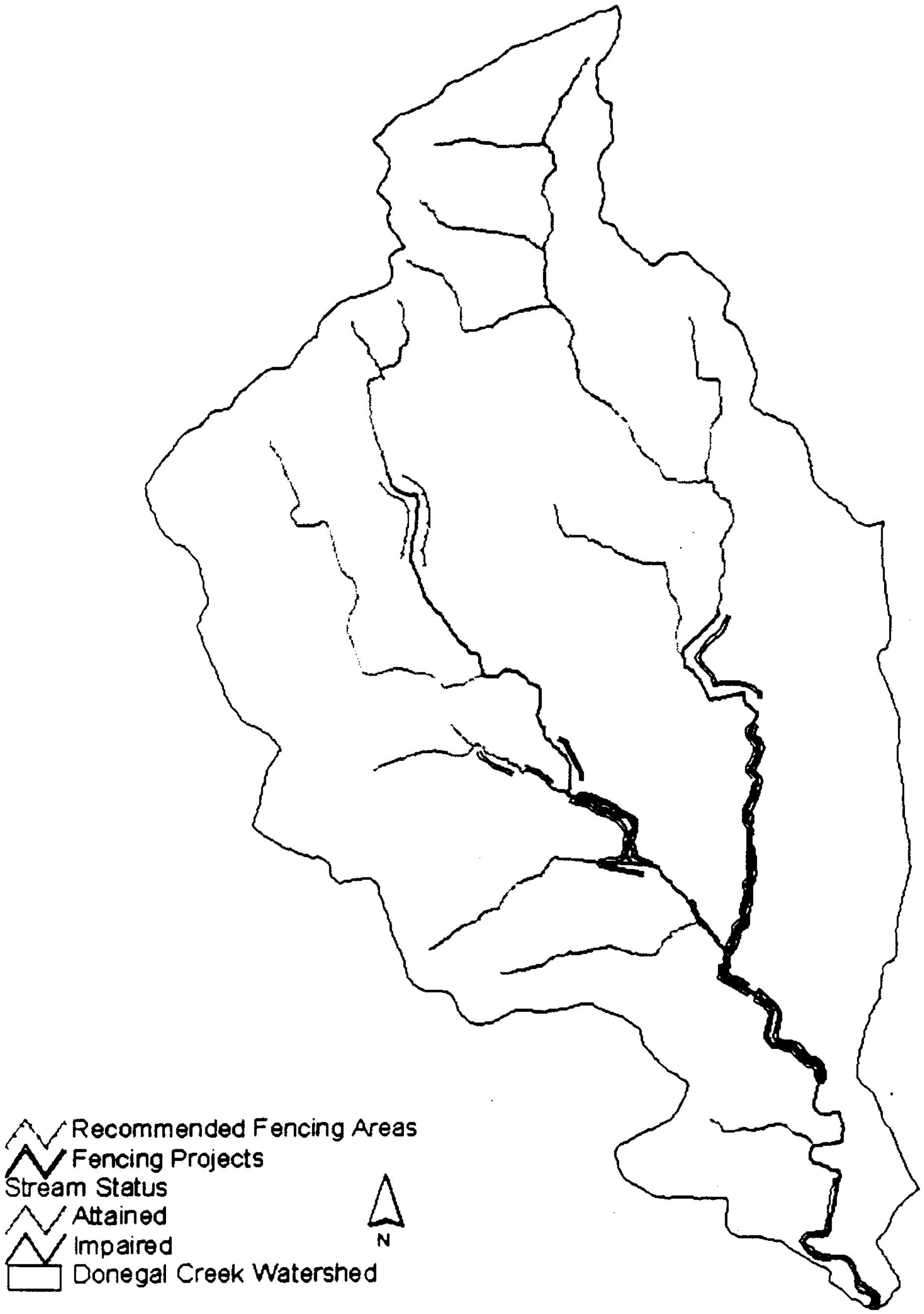
INITIAL UNSATURATED STORAGE (cm) = 10
INITIAL SATURATED STORAGE (cm) = 0
RECESSION COEFFICIENT (1/day) = .1
SEEPAGE COEFFICIENT (1/day) = 0
INITIAL SNOW (cm water) = 0
SEDIMENT DELIVERY RATIO = 0.180
UNSAT AVAIL WATER CAPACITY (cm) = 12

Attachment B

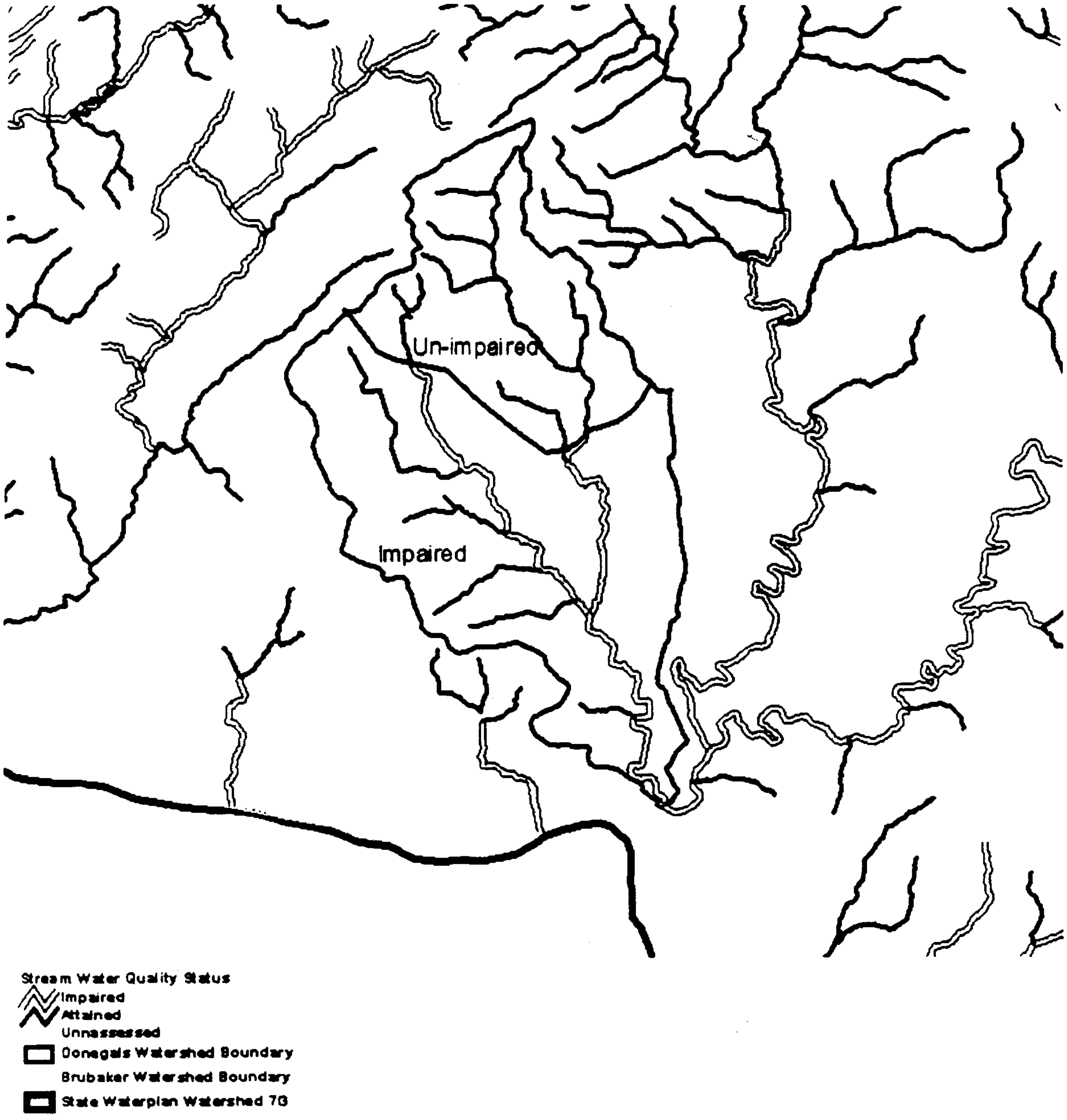
Map And Charts

Map 1

Donegal Creek Watershed
Stream Improvement Areas



Map 2. Impaired vs. Non-impaired Areas



Map 3

Land Cover Comparison

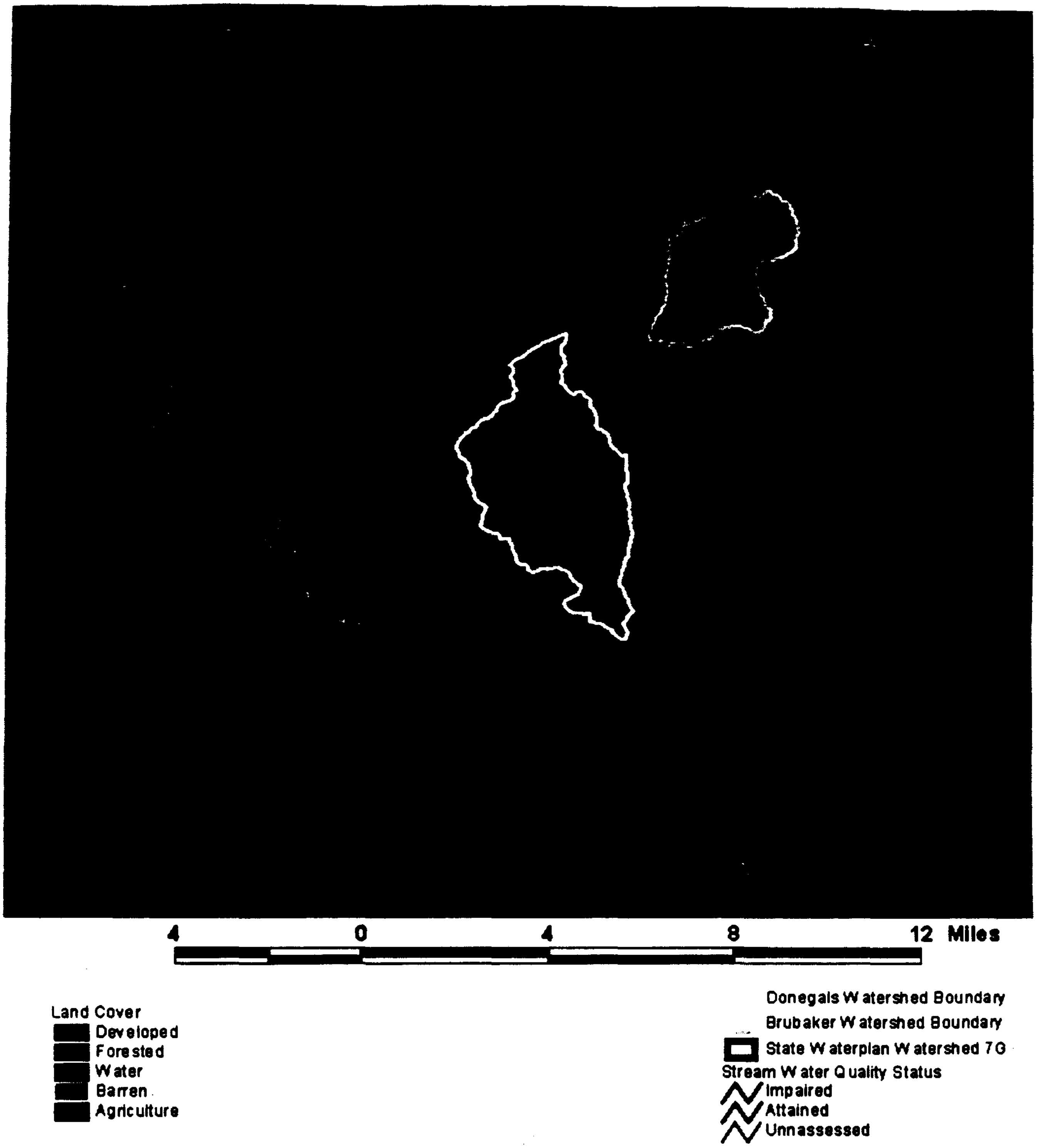
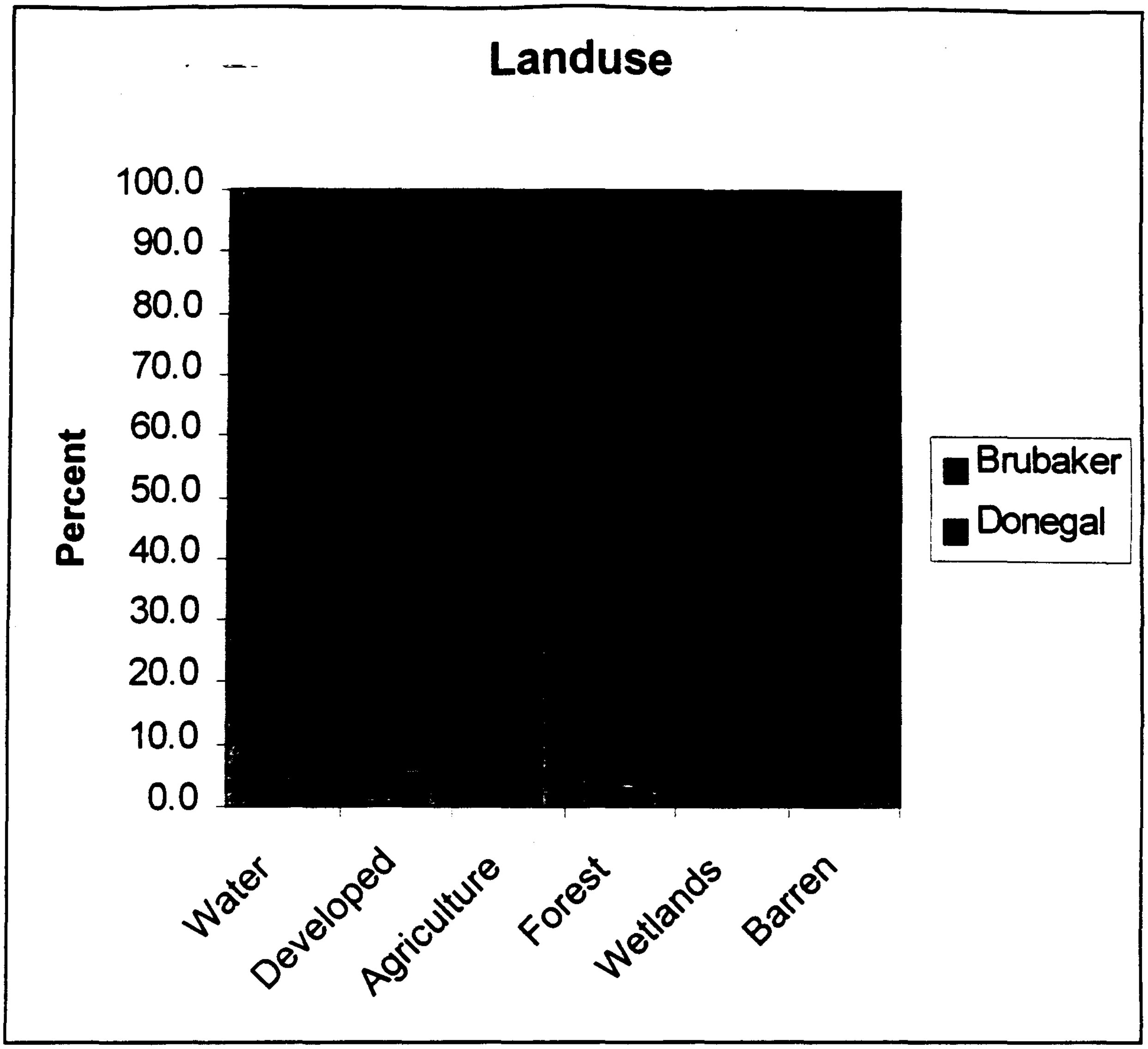


Chart 1. Land Cover Comparison



Information Sources for GWLF Model Parameterization.	
WEATHER.DAT file	Historical weather data from National Weather Service monitoring stations
TRANSPORT.DAT file	
Basin size	GIS/derived from basin boundaries
Land use/cover distribution	GIS/derived from land use/cover map
Curve numbers by source area	GIS/derived from land cover and soil maps
USLE (KLSCP) factors by source area	GIS/derived from soil, DEM, and land cover
ET cover coefficients	GIS/derived from land cover
Erosivity coefficients	GIS/ derived from physiography map
Daylight hrs. by month	Computed automatically for state
Growing season months	Input by user
Initial saturated storage	Default value of 10 cm (GWLF Manual)
Initial unsaturated storage	Default value of 0 cm (GWLF Manual)
Recession coefficient	Default value of .1 (GWLF Manual)
Seepage coefficient	Default value of 0 (GWLF Manual)
Initial snow amount (cm water)	Default value of 0 (GWLF Manual)
Sediment delivery ratio	GIS/based on basin size
Soil water (available water capacity)	GIS/derived from soil map
NUTRIENT.DAT file	
Dissolved N in runoff by land cover type	Default values (GWLF Manual)
Dissolved P in runoff by land cover type	Default values (GWLF Manual)
N/P concentrations in manure runoff	Default values (GWLF Manual)
N/P buildup in urban areas	Statewide atmospheric deposition layer
N and P point source loads	GIS/derived from NPDES point coverage
Background N/P concentrations in GW	GIS layer derived from USGS sample data
Background N/P concentrations in soil	GIS layer derived from soil test data
Months of manure spreading	Input by user
Population on septic systems	GIS/derived from census tract map
Per capita septic system loads (N/P)	Default values (GWLF Manual)

Attachment C

Strategy For Conducting Nutrient-Related TMDL Assessments for Streams in PA

Background

Nationwide recognition of the importance of non-point sources of pollution has led to increased efforts over the last two decades to identify and quantify non-point source pollutant loads, especially at the watershed level. Typical techniques for determining the extent and magnitude of non-point source pollution problems include long-term surface water monitoring and computer-based simulation modeling. Due to the time and expense associated with surface water monitoring, however, simulation modeling has been relied upon more frequently to provide needed information for the development and implementation of non-point source control programs (Novotny and Olem, 1994). Watershed simulation models, in fact, are commonly considered to be essential tools for evaluating the sources and controls of sediment and nutrient loading to surface waters. Such models provide a framework for integrating the data that describe the processes and land-surface characteristics that determine pollutant loads transported to nearby water bodies.

The utilization of watershed models, however, is a difficult, tedious task because of the broad spatial and temporal scales that must be considered, as well as the large amount of data that must be compiled, integrated, analyzed, and interpreted. Fortunately, the last two decades of model development have coincided with rapid advancements in the development and use of geographic information system (GIS) technology. This technology provides the means for compiling, organizing, manipulating, analyzing, and presenting spatially-referenced model input and output data. Due to the many inherent benefits, GIS software has been used to support literally hundreds of watershed modeling efforts over the last 10-15 years. Many state, regional, and federal environmental agencies, in fact, use this technology routinely to support ongoing watershed modeling and assessment programs (Samuels, 1998).

Over the last five years, the Pennsylvania Department of Environmental Protection (DEP) has recognized the indispensibility of GIS technology, and has endeavored to integrate it into all of the agency's internal program areas. Towards this end, researchers at Penn State's Environmental Resources Research Institute (ERRI) have been assisting DEP in the development and implementation of various GIS-based watershed assessment tools. One such tool facilitates the use of the GWLF (Generalized Watershed Loading Function) model developed by Haith and Shoemaker (1987) via a GIS software interface. As described below, this GIS-based modeling approach will be a key component in DEP's TMDL program.

The 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 considered to be a combined distributed/lumped parameter watershed model. For surface loading, it is distributed in the sense that it allows multiple land use/cover scenarios, but 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 simply 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 simply computed as the difference between precipitation and snowmelt minus surface runoff plus evapotranspiration.

With respect to the major processes simulated, 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 as follows: K = changes in soil loss erosion, LS = the length slope factor, C = the vegetation cover factor and P = conservation practices factor. A sediment delivery ratio based on watershed size and a transport capacity based on average daily runoff are then 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 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.

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 for GWLF

As described previously, the use of GIS software for deriving input data for watershed simulation models such as GWLF is becoming fairly standard practice due to the inherent advantages of using GIS for manipulating spatial data. To support watershed assessment projects, a customized interface for the ArcView GIS package was developed by Penn State for use in parameterizing input data for the GWLF model. In utilizing 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. For use in Pennsylvania, this ArcView-GWLF system (called 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. A summary of the sources used to derive the input data is given in Table 1.

A new module for "BMP Analysis" is presently being developed for AVGWLF. When completed, this module will provide the capability to conduct "what if" analyses for the purpose of determining the potential effects that various best management practices (BPMs) might have on nutrient and sediment loads produced within a given watershed. More specifically, the user will be able to select from a list of possible BMPs and to identify critical source areas within a watershed to which such BMPs would be applied. Subsequent to making selections for one or more "scenarios", the GWLF-simulated loads are then re-calculated using "efficiency" coefficients associated with each BMP type. The capability to view the results for each scenario, and to compare them against the original model results, will also be provided. (Note: This new module will probably not be available until early 2000).

General Approach to TMDL Analyses

As mentioned earlier, the GIS-based modeling approach described above (i.e., AVGWLF) will be used to perform nutrient-related TMDL analyses in Pennsylvania. The general sequence of steps will be as follows:

Table 1. Information sources for GWLF model parameterization.

WEATHER.DAT file	Historical weather data from National Weather Service monitoring stations
TRANSPORT.DAT file	
Basin size	GIS/derived from basin boundaries
Land use/cover distribution	GIS/derived from land use/cover map
Curve numbers by source area	GIS/derived from land cover and soil maps
USLE (KLSCP) factors by source area	GIS/derived from soil, DEM, and land cover
ET cover coefficients	GIS/derived from land cover
Erosivity coefficients	GIS/ derived from physiography map
Daylight hrs. by month	Computed automatically for state
Growing season months	Input by user
Initial saturated storage	Default value of 10 cm (GWLF Manual)
Initial unsaturated storage	Default value of 0 cm (GWLF Manual)
Recession coefficient	Default value of .1 (GWLF Manual)
Seepage coefficient	Default value of 0 (GWLF Manual)
Initial snow amount (cm water)	Default value of 0 (GWLF Manual)
Sediment delivery ratio	GIS/based on basin size
Soil water (available water capacity)	GIS/derived from soil map
NUTRIENT.DAT file	
Dissolved N in runoff by land cover type	Default values (GWLF Manual)
Dissolved P in runoff by land cover type	Default values (GWLF Manual)
N/P concentrations in manure runoff	Default values (GWLF Manual)
N/P buildup in urban areas	Statewide atmospheric deposition layer
N and P point source loads	GIS/derived from NPDES point coverage
Background N/P concentrations in GW	GIS layer derived from USGS sample data
Background N/P concentrations in soil	GIS layer derived from soil test data
Months of manure spreading	Input by user
Population on septic systems	GIS/derived from census tract map
Per capita septic system loads (N/P)	Default values (GWLF Manual)

- AVGWLF will be used to derive input data for GWLF, which will subsequently be used to simulate nutrient and sediment loads within the watershed.
- The pollutant loads simulated will be compared to those calculated for a nearby "reference" watershed that exhibits similar landscape, development and agricultural patterns, but which also meets selected stream quality criteria.
- An evaluation of BMPs will then be undertaken to identify possible BMPs that could be applied in the impacted watershed to achieve pollutant loads similar to those exhibited by the reference watershed.

For the purposes of conducting this type of analysis, summary information on land use/cover, surface geology, and per unit area nutrient loads is presented in Tables 2 through 4 for twenty-one reference watersheds within Pennsylvania. Table 5 gives reasonable values to use N and P concentration in runoff over agricultural and manured areas based on animal density, and Table 6 gives reasonable values for background P concentrations in soil based on existing fertilizer application rates. Table 7 has suggested reduction coefficients for various BMP strategies to reduce nonpoint source nutrient loads.

References

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

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

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, CO, pp. 1175-1182.

Table 2. Land Use/Cover Characteristics by Watershed

Watershed Name	Size (acres)	Percent Developed	Percent Wooded	Percent Water	Percent Disturbed	Percent Agriculture
Blacklick Creek	246,963	2.5	73.9	0.6	2.3	20.7
Brodhead Creek	192,404	4.2	86.5	1.4	0.1	7.8
Casselman Creek	204,804	1.6	61.2	0.2	2.2	34.8
Chartiers Creek	175,895	17.5	48.9	0.1	1.0	32.6
Clarion River	527,497	1.1	91.8	0.4	1.1	5.7
Clearfield Creek	241,353	1.0	80.6	0.6	3.9	13.9
Conewago Creek	326,715	2.7	32.4	1.0	0.2	63.8
Conodoguinet Creek	324,367	5.0	32.8	0.8	0.1	61.3
Juniata R./Raystown	460,165	1.2	64.6	0.4	0.5	33.4
Lehigh River	564,504	2.4	83.3	2.1	1.5	10.7
Oil Creek	208,888	1.0	76.9	0.1	0.3	21.8
Penns Creek	198,556	0.3	70.3	0.5	0.2	28.7
Pequea Creek	98,175	2.3	26.4	0.4	0.0	71.0
Pine Creek	630,630	0.2	88.5	0.3	0.5	10.5
Redbank Creek	340,213	2.2	70.9	0.2	1.8	24.9
Schuylkill River	224,279	3.8	74.8	1.8	5.0	14.6
Slippery Rock Creek	260,127	1.5	57.2	1.1	1.4	38.7
Spring Creek	73,612	6.1	44.0	0.3	0.1	50.0
Swatara Creek	365,545	5.7	43.8	0.9	0.8	48.8
Tunkhannock Creek	264,777	1.5	68.0	1.9	0.0	28.6
Wisahickon Creek	40,756	42.3	40.7	0.2	0.7	16.1

Table 3. Geologic Characteristics by Watershed

Watershed Name	Percent Carbonate	Percent Cong[1]	Percent IBS[2]	Percent Meta/Ig[3]	Percent Sandstone	Percent Shale	Percent Uncon[4]	Glaciated
Blacklick Crk	-	-	98.1	-	1.9	-	-	No
Brodhead Crk	-	-	41.4	-	47.2	11.4	-	Half
Casselman	-	-	84.6	-	15.4	-	-	No
Chartiers Crk	-	-	94.6	-	-	5.4	-	No
Clarion Crk	-	-	43.0	-	57.0	-	-	No
Clearfield Crk	-	-	87.7	-	12.3	-	-	No
Conewago	9.8	5.6	-	31.8	23.2	29.6	-	No
Conodoguinet	39.0	-	5.5	2.7	8.1	44.7	-	No
Juniata/Rays	11.3	-	49.5	-	23.1	16.1	-	No
Lehigh	-	-	40.9	-	54.2	4.9	-	Half
Oil Creek	-	-	30.4	-	47.9	21.7	-	Half
Penns Crk	23.7	-	-	-	46.7	29.6	-	No
Pequea Crk	51.8	6.2	-	38.3	-	3.7	-	No
Pine Creek	-	-	47.0	-	53.0	-	-	Partial
Redbank Crk	-	-	75.8	-	24.2	-	-	No
Schuylkill R	1.4	-	54.2	-	35.7	8.7	-	No
Slippery Rock	-	-	76.1	-	22.3	1.6	-	Half
Swatara Crk	14.8	0.7	54.0	2.0	12.2	15.3	-	No
Tunkhannock	-	-	100	-	-	-	-	Yes
Wisahickon	16.5	8.1	-	20.5	33.9	19.4	1.6	No

[1] Conglomerate
[2] Inter-Bedded Sedimentary (limestone, dolomite, sandstone, siltstone, shale, etc.)
[3] Metamorphic/Igneous
[4] Unconsolidated

Table 4. Pollutant Load Characteristics by Watershed

Watershed Name	Point Load N (lbs/ac)	NPS Load N (lbs/ac)	Total Load N (lbs/ac)	Point Load P (lbs/ac)	NPS Load P (lbs/ac)	Total Load P (lbs/ac)	Sediment (lbs/ac)
Blacklick Crk	-	3.13	3.13	-	0.13	0.13	
	0.36	2.96	3.32	-	0.63	0.63	
Brodhead Crk	0.04	9.35	9.39	-	0.44	0.44	
Casselman	0.25	5.37	5.62	-	0.57	0.57	
Chartiers Crk	0.11	2.52	2.63	-	0.18	0.18	
	-	4.04	4.04	-	0.20	0.20	
Clarion River	0.46	14.12	14.58	0.21	0.20	0.41	
Clearfield Crk	0.35	14.44	14.79	0.26	0.03	0.29	
	0.12	7.82	7.94	0.02	0.24	0.26	
Conewago	0.02	5.11	5.13	-	0.40	0.40	
Conodoguinet	0.22	2.75	2.97	-	0.34	0.34	
Juniata/Rays	-	10.08	10.08	-	0.20	0.20	
	-			-			
Lehigh	0.01	2.80	2.81	-	0.11	0.11	
Oil Creek	0.14	3.85	3.99	-	0.23	0.23	
Penns Crk	0.99	7.91	8.90	-	0.32	0.32	
Pequea Crk	0.03	3.11	3.14	-	0.21	0.21	
Pine Creek	0.30	11.13	11.43	-	0.18	0.18	

Redbank Crk	0.73	15.57	16.30	0.39	0.09	0.39	
Schuylkill R	-	3.47	3.47	-	0.20	0.20	
Slippery Rock	1.40	17.17	18.57	-	3.48	3.48	
Spring Creek							
Swatara Crk							
Tunkhannock							
Wisahickon							

Table 5. Suggested N and P Values (mg/l) Based on Animal Density

GWLF Parameter	**Animal Equivalent Units** **≤ 1.5**	 **1.5 – 2.5**	 **≥ 2.5**
N in agricultural areas	1.9	2.9	4.4
N in runoff from manured areas	8.1	12.2	18.3
P in agricultural areas	0.3	0.4	0.5
P in runoff from manured areas	2.0	3.0	4.0

Table 6. Suggested P Values (mg/kg) Based on Fertilizer Loading

GWLF Load (mg/kg)	**Pounds Per Acre**
1800	40 – 60

1900	60 – 80
2000	80 – 100
2100	100 – 120
2200	120 – 140
2300	>140

Table 7. Nutrient Reduction Coefficients for Various BMP Strategies

	Reduction Factor (%)		
BMP	**N**	**P**	**Sediment**
Conventional to conservation tillage	4	8	8
Incorporation of hayland in crop rotation	4	8	8
Incorporation of pasture in crop rotation	20	14	14
Streambank stabilization and fencing	75[1]	75[1]	75
Nutrient management plan	75[2]	75[2]	75

[1] Only applies to surface component of nutrient loads

[2] Reduction factor should only be used for either N or P; not both

Attachment D

Introduction to Watershed Hydrology, Simulation, and Pollutant Transport

By

Barry Evans

INTRODUCTION

Primarily because of public interest in addressing perceived water quality problems associated with the nation's lakes, rivers and streams, the Clean Water Act (CWA) of 1972 was established to reduce pollutant discharges from factories, sewage treatment plants, and other similar "point" sources of pollution. One result of the CWA has been the expenditure of approximately $95.9 billion during the last 25 years for use in upgrading the nation's wastewater treatment plants, which has improved the average efficiency of biological oxygen demand (BOD) removal from such sources from about 63% in 1968 to about 85% in 1996 (Stoddard et al., 1998). Similar levels of pollutant reduction have also been achieved by non-public point source dischargers during this same period, owing largely to effluent standards established by the CWA.

Despite the expenditure of significantly large sums of both public and private funds, however, widespread improvements in the quality of surface waters have not necessarily been achieved uniformly across the country. This lack of uniform improvement is principally due to the fact that "non-point" sources of pollution are as important (and in many instances, more important) than the traditional point sources in many areas of the country. In the early 1980s, it was estimated that non-point sources contributed significant percentages of such pollutants as BOD (57%), nutrients (87% of phosphorus and 88% of nitrogen), and total suspended solids (98%) (Gianessi and Peskin, 1981). Similarly, in a 1988 report to Congress, the U.S. Environmental Protection Agency (USEPA) indicated that agricultural activities were the principal cause of water quality problems related to surface and ground water (USEPA, 1990).

This recognition of the importance of non-point sources of pollution has led to increased efforts over the last two decades to identify and quantify non-point source pollutant loads, especially at the watershed level. Typical techniques for determining the extent and magnitude of non-point source pollution problems include long-term surface water monitoring and computer-based simulation modeling. Due to the time and expense associated with surface water monitoring, however, simulation modeling has been relied upon more frequently to provide needed information for the development and implementation of non-point source control programs (Novotny and Olem, 1994). Watershed simulation models, in fact, are commonly considered to be essential tools for evaluating the sources and controls of sediment and nutrient loading to surface waters. Such models provide a framework for integrating the data that describe the processes and land-surface characteristics that determine pollutant loads transported to nearby water bodies. Excellent historical overviews on the utility of computer models for quantifying and analyzing pollution problems within watersheds throughout the country over the past three decades are provided by DeCoursey (1985), Moore (1991), Poiani and Bedford (1994), and Wilson (1996).

The utilization of watershed models, however, is a difficult, tedious task because of the broad spatial and temporal scales that must be considered, as well as the large amount of data that must be compiled, integrated, analyzed, and interpreted. Fortunately, the last two decades of model development have coincided with rapid advancements in the development and use of geographic information system (GIS) technology. This technology provides the means for compiling, organizing, manipulating, analyzing, and presenting spatially-referenced model input and output data. Due to the many inherent benefits, GIS software has been used to support literally hundreds of watershed modeling efforts over the last 10-15 years. Many state, regional, and federal environmental agencies, in fact, use this technology routinely to support ongoing watershed modeling and assessment programs (Samuels, 1998).

As suggested above, simulation models are being applied more frequently to "real-world" pollution problems, and given the U.S. EPA's new watershed-based emphasis, this trend is likely to continue. Similarly, given the rapid development of GIS databases throughout the country, it is also likely that GIS-based watershed modeling will become a standard analytical approach in the foreseeable future. Consequently, it will become imperative that appropriate GIS data sets which accurately reflect the spatial variability of critical model parameters be used to derive input data for such modeling efforts. This will be especially important as "total maximum daily loads" are developed for watersheds as required by the 1972 Clean Water Act (see Paulson and Dilks, 1996).

Over the last five years, the Pennsylvania Department of Environmental Protection (DEP) has recognized the indispensibility of GIS technology, and has endeavored to integrate it into all of the agency's internal program areas. Towards this end, the author has been assisting DEP in the development and implementation of various GIS-based watershed assessment tools. One such tool facilitates the use of the GWLF model via a GIS software interface.

HYDROLOGY, SOIL EROSION, AND NUTRIENT TRANSPORT PROCESSES

Hydrology

Generally speaking, the movement of "non-point source" pollutants (e.g., sediment, nutrients, and pesticides from cultivated areas) primarily occurs during "wet weather" conditions (i.e., during and/or shortly after precipitation events). This is not entirely true since, as described later, some movement does occur as a result of subsurface ground water flow. However, regardless of the primary mode of pollutant transport, for those engaged in simulation modeling activities, it is important to know something about the fundamental hydrologic processes that operate in a typical watershed.

Classically, the movement of water between the planet's oceans, atmosphere, and land bodies is referred to as the *hydrologic cycle*. With respect to watershed studies, the primary focus is on the land-based portion of the cycle. A generalized view of hydrologic processes operating in a watershed is shown in Figure 1. As shown in this figure, precipitation falling on a given landscape (as either rain or snow) can leave the land surface via *evapotranspiration* (ET), infiltrate into the soil surface and subsequently move as shallow subsurface flow or *interflow* (IF), move through the soil profile and enter much deeper ground water flow systems as *groundwater recharge* (GWR), or move across the land

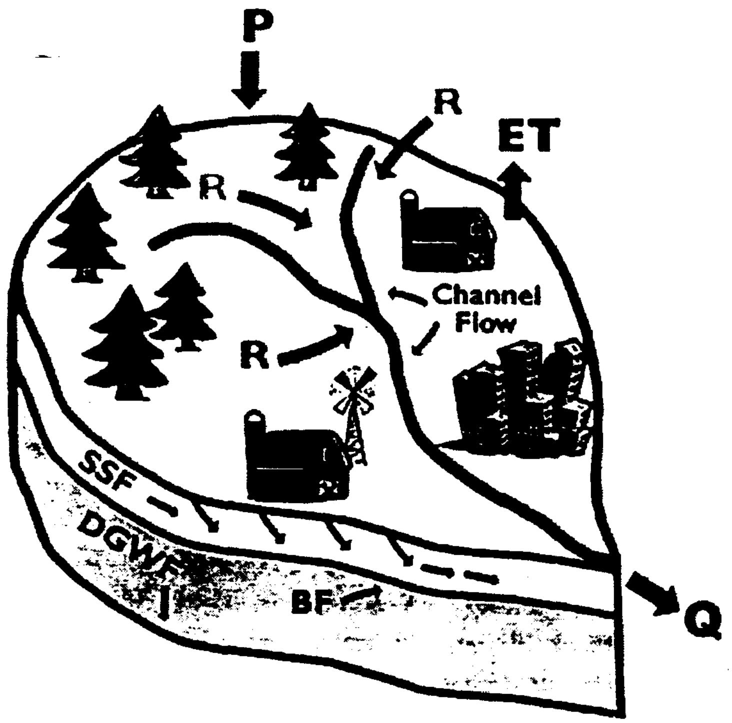


Figure 1

surface as *overland flow* (i.e., surface runoff - R). Another component of subsurface flow is *baseflow* (BF), which originates from deep groundwater storage. Baseflow is considered to comprise most of the streamflow during prolonged periods of drought.

Evapotranspiration is a term which describes a combination of evaporation from open bodies of water, evaporation from soil and other land surfaces, and transpiration by plants. As implied above, water that does not leave via evapotranspiration can either enter streams via surface runoff or enter the soil via infiltration. Rates of infiltration are largely controlled by surface characteristics, such as depressions and vegetation, and subsurface characteristics, such as soil permeability and fractures, and have considerable influence on the timing and spatial distribution of surface water runoff.

Soil Erosion

Erosion is the removal of a mass of soil from one part of the land surface and it's subsequent relocation to another part (i.e., deposition). Soil erosion due to moving water is a serious threat to the quality of the soil, land, and water resources upon which man depends for his sustenance. As an indication of the severity of this problem, Pimentel et al. (1995) estimated world-wide costs of soil erosion to be about four hundred billion dollars per year.

Water-induced soil erosion is typically divided into two basic types: *sheet erosion*, or *rill* and *gully erosion*. *Sheet erosion* (sometimes referred to as *interrill* erosion) is best described as the process of detachment and transport of soil by raindrops and very shallow flow (Sharma, 1996).

This type of erosion is fairly constant over a given slope as long as the soil and other surface properties remain relatively unchanged (Young and Wiersma, 1973). Interrill processes generally occur within a meter or so of the point of impact of a water drop, and delivers soil (and other) material to nearby channels. Surface runoff in these nearby channels then delivers this material to points farther down-stream. Rill and gully (or channel) erosion is the process of detachment and transport of soil due to flowing water. This type of erosion is distinctly and visibly different than interrill erosion, but the distinction is sometimes blurred at the boundary between the area where interrill processes occur and where channel processes occur.

The total amount of erosion that may occur during a given time period as a result of the processes described above is often referred to as the gross, or potential, erosion. This should be distinguished, however, from *sediment yield*, which is the actual amount of sediment that reaches receiving bodies of water during the same time period. There is generally a fairly large difference between the amount of soil erosion occurring within a watershed and the actual sediment yield, and this difference is largely controlled by the counteractive process of deposition. The sediment yield is thus determined by the relative magnitudes of the rates of erosion and deposition which are, in turn, affected by such factors as the composition of surficial material (i.e., consolidated or unconsolidated), soil particle size and texture, water content, and the presence or absence of protective surface cover such as vegetation (Walling and Webb, 1983).

Nitrogen Sources and Transport Processes

Nitrogen is one of the most common elements on the planet. It is one of the four essential elements that form the basic structure of protein (along with carbon, oxygen, and hydrogen), and is also the most abundant gas in the atmosphere. The primary forms of nitrogen found in the atmosphere are N_2 (nitrogen gas), No_x (various nitrogen oxides), and NH_4 (ammonia). The primary forms found on and in the soil include NH_4, NO_2, NO_3, and various organic forms found in plants, animals and other soil organisms. The nitrogen cycle is a concept used to describe the behavior and processes involved in the transfer of nitrogen between the principal components of the environment (i.e., air, land and water). It can be argued that an equilibrium with respect to the distribution of nitrogen more or less exists naturally, and that pollution occurs when conditions or activities (usually related to man) cause an imbalance in the amount of naturally existing forms of nitrogen in one or more components of the air-land-water environment. For example, there are optimal ratios of NO_3/N for various terrestrial and aquatic organisms; as the balance becomes tipped, some organisms become predominant and the environment becomes unfavorable for others.

With respect to water pollution, nitrogen becomes problematic when it occurs in amounts that exceed the natural assimilative capacity of water bodies. In surface water (especially relatively slow-moving bodies such as lakes, estuaries, and bays), excessive nitrogen loads can lead to a condition called *eutrophication*, which leads to excessive algae and aquatic plant growth. This growth can cause oxygen depletion in the water when the algae and plants decompose, which often results in fish kills, foul odors and unpleasant tastes. High levels of nitrates in both surface and ground water also render it unhealthy for humans as a source of drinking water. Nitrogen is one of the most important pollutants entering surface water via direct discharge from sewage treatment plants. As a non-point source (or diffuse) pollutant, nitrogen primarily enters surface water as dissolved NO_3 and NH_4 in surface runoff and interflow from land, or as NH_4 attached to soil particles in surface runoff.

As a pollutant, nitrogen has been a problem to some degree for someone somewhere ever since the advent of man. In antiquity, water pollution problems stemmed primarily from inadequate (or indiscriminate) disposal of human excreta as well as from the use of animal wastes as a natural fertilizer in cultivating crops. Water pollution problems undoubtedly existed wherever man collected in groups, but problems did not generally become "regional" problems until man began collecting human wastes in urban areas (via sewers) and depositing the wastes in nearby surface water bodies. This practice reduced the spread of disease due to contact with human waste in urban areas (as was its intention), but it resulted in the occurrence of localized water pollution problems wherever waste loads overcame the assimilative capacities of the bodies of water into which the wastes were discharged. It was at this time that nitrogen, which was previously a diffuse pollution problem, became a point source problem.

As population levels increased, and increasingly more land was used for residential, commercial, industrial, and agricultural purposes, the importance of nitrogen as a surface water pollutant also increased. As a non-point source pollutant, nitrogen has historically been thought to originate primarily from agricultural activities (both via crop cultivation and animal husbandry); non-agricultural fertilization of lawns, golf courses, and other non-farm turfgrass areas (e.g., cemeteries and grassy areas around commercial and institutional buildings); on-lot septic systems in suburban and rural areas; and urban areas as a result of stormwater runoff. However, over the last twenty years, it has been irrefutably demonstrated that a major (if not the primary) source of nitrogen as a diffuse pollutant in many regions of the U.S. is atmospheric deposition (Fangmeir et al., 1994; Tyler, 1988; and U.S. EPA, 1995). In California, it is estimated that between 1 - 40 kg/ha/yr falls in the form of wet or dry deposition (Bytnerowicz, 1996). Similarly, in a recently completed study in Pennsylvania, Nizeyimana et al. (1997) reported on the sources and relative contributions of various types of non-point pollution to surface and ground water within the state. They calculated that atmospheric deposition and agricultural activities account for about 88% of the non-point source nitrogen load to surface and ground water.

Within the U.S., there are distinct regional differences with respect to the relative importance of different sources of nitrogen in causing water pollution. For example, point source discharges account for more than 75% of the total nitrogen load to the South Platte River in Colorado; although point sources accounted for only about 5% of the total load to surface water nationwide as compared to over 90% from agricultural sources (Puckett,1994). In western parts of the U.S. where agriculture is intensive, fertilizers are the dominant source of nitrogen, followed by atmospheric deposition. In some regions of central and eastern U.S. where animal production is important, such as the White River basin in Arkansas, animal manure is an important non-point source of nitrogen. In the northeastern part of the U.S. where agriculture is less intensive, atmospheric deposition is the dominant source of nitrogen in most watersheds, such as the Connecticut River, where atmospheric deposition accounts for about 60% of the total nitrogen load.

It is very difficult to describe in precise terms the variety of processes and pathways involved in the delivery of-nitrogen (in it's many forms) to surface water. However, the primary ways in which nitrogen (as a diffuse pollutant) is cycled through the air-land-water environment are summarized below:

- Nitrogen exists primarily as No_x and NH_4 in the atmosphere, and it is generally assumed that these are the primary forms transferred to land via wet and dry deposition. Industrial/urban areas are the major sources of nitrogen oxide emissions in the atmosphere. About 63% of this load is contributed by highway vehicles, electric power plants and industrial combustion; and about 37% comes from agricultural sources (primarily via ammonia volatilization and nitrification/denitrification processes operating on nitrogen in manure and commercial fertilizers).

- Atmospheric nitrogen is deposited on both open water as well as land surfaces. Nitrogen falling on land surfaces is not necessarily distributed uniformly; deposition rates, in fact, are largely determined by regional weather conditions. The amount of nitrogen from such sources that ultimately ends up in surface water bodies via surface runoff is heavily influenced by the type of land surface on which it falls (for instance, much of the nitrogen falling on forested areas is absorbed by vegetation as compared to urban areas where most of it is transported to surface water via runoff).

- In cultivated areas, the atmospherically deposited load is augmented by nitrogen contained in manure applied as a fertilizer (primarily NH_4), commercial fertilizers (primarily NO_3), and plant residue. Significant nitrogen loads also originate from areas where farm animals are located such as pastures and confined feedlots (with the latter having much higher per unit area loading rates). In these areas, nitrogen is primarily transported to surface water via attachment to sediment and in a dissolved state in surface runoff and shallow subsurface flow. As indicated above, much of the applied nitrogen load makes it's way back to the atmosphere via volatilization.

- In urban and suburban areas, the atmospherically deposited load is augmented by nitrogen (primarily nitrates) from on-lot septic systems and turfgrass fertilization, as well as a relatively small amount of organic and inorganic nitrogen from street debris. Nitrogen is primarily transported from these areas to nearby surface water via interflow (as is the case with turfgrass fertilization and septic systems) and direct surface runoff, as is the case with urban runoff and septic systems that are 'breaking out' at the surface. As indicated earlier, urban areas are also a major source of atmospheric nitrogen which is subsequently re-deposited on urban and other areas.

Phosphorus Sources and Transport Processes

Phosphorus is an important nutrient which affects various growth processes in both animals and plants. Similar to nitrogen, excessive phosphorus in surface water can also lead to eutrophication problems. In fact, in many cases, phosphorus has been found to be the limiting factor in the eutrophication of selected water bodies (Ryden et al., 1973; Jones and Lee, 1982; and Browne, 1982). Increasing levels of phosphorus in surface water, along with other nutrients, has also been linked to the sporadic outbreaks of waterborne organisms such as *Pfisteria piscicida*, which has been reported to cause intenstinal ailments in the Chesapeake Bay region.

Phosphorus in nature is usually found in one of its various phosphate forms, with the most common ones being orthophosphate, metaphosphate, and organically bound phosphate. Orthophosphates are found in sewage and are a common by-product of many natural biodegradation processes. The more complex metaphosphates are found in detergents, and are also used in treating boiler water. Organic forms may result from the breakdown of organic pesticides, and may exist in solution, as particles, loose fragments, or in the bodies of organic organisms.

By far, most of the phosphorus that reaches surface water bodies is a result of activities that take place in agricultural areas around the world (Sharpley, 1994; Heathwaite, et al., 1996; Lennox et al., 1997; and Hetling et al., 1998). In the soil, phosphorus (P) exists in both organic and inorganic forms. Inorganic forms (e.g., orthophosphate) originate from a class of minerals known as apatites. These minerals are insoluble calcium phosphates existing in several forms, and the orthophosphate ions are generated via chemical weathering processes. The primary source of organic P is plant and organic biomass residues. Other important sources of P in agricultural (as well as rural) areas include commercial fertilizers and manure, land application of sludge (biosolids) from wastewater treatment plants, livestock grazing, non-agricultural fertilization, and on-lot septic systems..

Past research has indicated that erosion from agricultural land is a major source of diffuse phosphorus transfer (Boardman, 1990; and Lennox et al., 1997). This erosion, in the form of suspended sediment transfer, is often associated with high rates of particulate P transfer from land to surface water bodies. Unlike nitrogen, phosphorus is not particularly mobile in soils, and phosphate ions do not leach readily. Consequently, P in most agricultural watersheds is removed from soils either via crop uptake or erosion. As reported by Sharpley and Syers (1979) and Pionke et al. (1996), however, the surface and subsurface composition of a given watershed can result in significantly high contributions of P from shallow subsurface flow as well; particularly in watersheds dominated by limestone geology. Additionally, bank erosion and re-suspension of P in stream-bed loads can contribute significant portions of the overall P load of streams that drain both agricultural and non-agricultural areas (Sharpley and Syers, 1979).

In general, phosphorus loss is primarily determined by the coincidence of source factors (i.e., functions of soil, crop and management) and transport factors (i.e., surface and subsurface runoff, erosion and channel processes) (Gburek and Sharpley, 1998). Source factors are those most closely related to a watershed's potential for contributing P from diffuse sources, and transport factors are those which determine whether this potential results in phosphorus losses. Some of the principal factors which influence P loss in agricultural watersheds, as observed by Heathwaite and Sharpley (1998), are summarized in Table 1.

Table 1. Principal source and transport factors affecting

phosphorus loss in agricultural watersheds.

P SOURCES	P TRANSPORT
Soil Factors • Soil P concentration • Soil texture, structure, permeability • Erosion risk *Land Management* • Land use • Cultivation practice • Fertilizer inputs, forms, timing • Manure inputs, forms, timing • Biosolids inputs, timing • Livestock grazing density	*Spatial Factors* • Topography • Incidence of surface runoff • Contribution from subsurface flow • Location relative to drainage network *Temporal Factors* • Precipitation duration • Precipitation intensity • Precipitation magnitude • Storm return period

Fundamental Properties and Characteristics of Watershed Models

As described in detail by Chow et al., (1988), Novotny and Olem (1994) and others, most simulation models that operate at the watershed scale can be described as being deterministic or indeterministic, lumped or distributed, and/or single event or continuous simulation models.

Indeterministic models, expressed either in probabilistic or stochastic terms, define the physical system such that they pre-suppose the outcome to be uncertain and random. Stochastic models, therefore, have some components that are random with a probability through the time domain, and their outputs can be expressed in terms of mean and probability range. A deterministic model ignores the input of random pertubations and random variations of system parameters, and defines the physical system in such a way that the occurrence of a given set of events (i.e., model inputs) leads to only one possible outcome.

Deterministic models can be further subdivided into lumped or distributed models, depending on how the spatial domain is addressed. With a lumped model, the watershed is represented as being a spatially homogenous unit, and no consideration is given to variations in inputs within the system. Distributed models, on the other hand, assume that the watershed is comprised of smaller, uniform, and discrete sub-units; with each unit being characterized by a uniform set of properties and input parameters.

Finally, lumped and distributed models can be classified as continuous or event-based, depending on the time scale of interest. For example, event-based models are generally used to simulate watershed responses to single precipitation events (or events of very short duration). Continuous models, however, simulate transport processes over a specified time interval (which may range from fractions of an hour to years), and provide a time series of model outputs.

Potential Approaches to GIS-Based Modeling

A number of approaches to using GIS for hydrologic modeling are possible. The principal ones include hydrologic assessment, hydrologic parameter estimation, hydrologic modeling within a GIS, and direct linkage between GIS and hydrologic models. Although this paper will focus on the use of GIS for parameter estimation, an overview of all of the above methods is provided below.

Hydrologic Assessment

Hydrologic assessment refers to the use of GIS for the analysis of various hydrologic factors for the purpose of assessing risk or susceptibility to pollution. One example of this type of analysis is the use of GIS for evaluating groundwater contamination potential using the DRASTIC ranking technique developed by the U.S. EPA (Evans and Myers, 1990). Another example is the non-point source assessment technique described by Hamlett et al. (1992). This type of spatial modeling is not based upon a rigorous simulation of physical, chemical or biological processes, but rather uses weighted indexing schemes to quantify the relative influence of various factors in contributing to pollution problems.

Hydrologic Parameter Estimation

Parameter estimation is probably the most active area in the GIS field related to hydrology. In this case, the objective is to determine and quantify parameters that can be used as input to hydrologic models via the manipulation and analysis of various terrain-related data sets. Reported in the literature are numerous examples where information on land slope, channel slope, soil characteristics and land cover was derived from digital raster and vector data layers for this purpose (e.g., Peterson and Hamlett, 1998; Yagow and Shanholtz, 1996; Ross and Tara, 1993). In this case, various GIS routines are used to overlay a digital AGNPS sub-area layer with another layer depicting a particular parameter, sum the parameter cell values within the area bounded by each AGNPS cell (i.e., sub-area), and calculate the average value (Evans and Miller, 1988). It is not necessary that the sub-area cells and GIS cells be the same size. In fact, the spatial resolution of GIS data cells is almost always an order of magnitude finer than that of the AGNPS sub-area cells.

Another way in which a GIS can be used to derive hydrologic parameters is via linkage to a library of geo-referenced parameter values. For example, the SWRRBWQ model (Simulator for Water Resources in Rural Basins - Water Quality version) has a library of weather parameters defined for about 100 weather stations in the U.S. so that estimates of required climatic variables can be extracted automatically for modeling purposes (Arnold et al., 1990). Likewise, for soils information, SWRRBWQ has detailed data on soil properties for hundreds of soil types as depicted on county-level SCS soil maps. Similar "default parameterization" approaches are also used for the SWAT (Soil and Water Assessment Tool) model, which is the successor to the SWRRB series of models. Descriptions of how GIS has been used to automate the parameterization process for these particular models have been provided by Evans et al. (1992), Rosenthal et al. (1993), and Bian et al. (1995).

Hydrologic Modeling Within a GIS

It is also possible to perform varying degrees of hydrologic modeling directly within a GIS, so long as time variability is not an issue. This is the case when considering annual averages of variables such as annual average flow or pollutant loadings from a watershed. For example, one could implement spreadsheet-type models in which flows or loadings are computed as flow or load per unit area times the area (Evans et al., 1994). As described by Smith et al. (1993), one could also capture some more complex equations, such as those for pollutant loadings derived via regression, where the independent variables in the regression equations are mapped in coverages and then the loadings are worked out based on mathematical combination of coverage data.

Another way of eliminating time as a variable is to take a snapshot at the peak flow condition and model that by assuming the discharge is at peak value throughout the system (Chieng and Luo, 1993). It is thus possible to route water through GIS networks using analogies to traffic flow routing in which each line segment (arc) is assigned an impedance measured by flow time or distance, and flow is accumulated going downstream through the network. A limitation of this type of modeling is that it is difficult to specify the impedance without knowing the flow, and it is at the same time difficult to calculate the flow without first knowing the impedance.

It seems theoretically possible that one-dimensional and two-dimensional computations could be done explicitly based on a GIS database of river channels (for 1-D flow) or shallow lakes and estuaries (for 2-D flow). This approach is not commonly used within GIS systems at this time, however. Some examples of work in which hydrologic modeling routines were developed within a GIS system include Vieux et al. (1988), Hodge et al. (1988), Wolfe and Whittaker (1990), Stallings and Smollen (1990), and Robinson and Ragan (1993).

Direct Linkage Between GIS and Hydrologic Models

This is an active area of research, especially in connection with groundwater flow. Two-dimensional finite difference and finite element programs have been linked to GIS for spatial data input to the flow computation and for display of results, such as piezometric head surfaces or contaminant plumes (Corwin et al., 1993). These models are spatially distributed and rely fairly heavily on the topological representation of the flow domain in GIS as compared to a lighter emphasis on the descriptive attributes attached to the spatial features. Finite difference and finite element methods are more difficult to solve in surface water flow than in slowly moving groundwater, however, because the numerical instabilities that result due to the higher velocities are more difficult to remove.

In general, there does not appear to be as much work involving the direct linkage of GIS and surface water models as there has been with groundwater models. Some exceptions, however, include the very innovative work conducted by SCS (Cronshey, Theurer and Glenn, 1993) and the University of Texas (Djokic, 1993; Evans, Djokic and Maidment, 1993). In the former case, the objective was to imbed several existing physically-based watershed models into a public domain GIS package (GRASS). In the latter case, several watershed models were directly linked with ARC/INFO software via the use of an object-oriented expert system shell (Nexpert Object). Both these and other similar research efforts have provided some exciting developments for the GIS/hydrologic modeling community.

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Attachment E

GWLF Users Manuel

GWLF

GENERALIZED WATERSHED LOADING FUNCTIONS

VERSION 2.0

USER'S MANUAL

December 15, 1992

Douglas A. Haith, Ross Mandel & Ray Shyan Wu

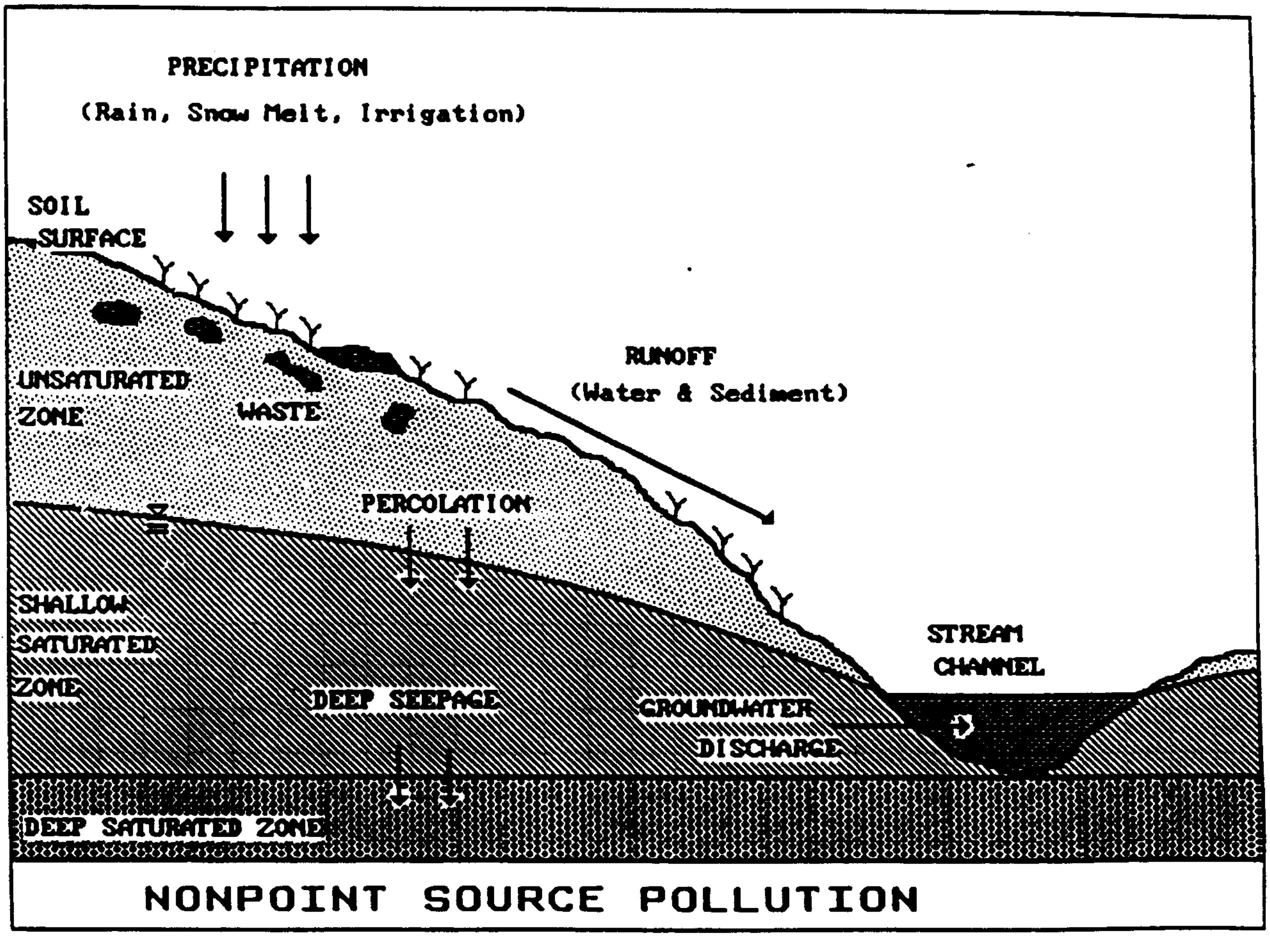

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TABLE OF CONTENTS

INTRODUCTION

Mathematical models for estimating nonpoint sources of nitrogen and phosphorus in streamflow include export coefficients, loading functions and chemical simulation models. Export coefficients are average annual unit area nutrient loads associated with watershed land uses. Coefficients provide gross estimates of nutrient loads, but are of limited value for determining seasonal loads or evaluating water pollution control measures. Chemical simulation models are mechanistic (mass balance) descriptions of nutrient availability, wash off, transport and losses. Chemical simulation models provide the most complete descriptions of nutrient loads, but they are too data intensive for use in many water quality studies.

Loading functions are engineering compromises between the empiricism of export coefficients and the complexity of chemical simulation models. Mechanistic modeling is limited to water and/or sediment movement. Chemical behavior of nutrients is either ignored or described by simple empirical relationships. Loading functions provide useful means of estimating nutrient loads when chemical simulation models are impractical.

The Generalized Watershed Loading Functions (GWLF) model described in this manual estimates dissolved and total monthly nitrogen and phosphorus loads in streamflow from complex watersheds. Both surface runoff and groundwater sources are included, as well as nutrient loads from point sources and on-site wastewater disposal (septic) systems. In addition, the model provides monthly streamflow, soil erosion and sediment yield values. The model does not require water quality data for calibration, and has been validated for an 85,000 ha watershed in upstate New York.

The model described in this manual is a based on the original GWLF model as described by Haith & Shoemaker (1987). However, the current version (Version 2.0) contains several enhancements. Nutrient loads from septic systems are now included and the urban runoff model has been modified to more closely approximate procedures used in the Soil Conservation Service's Technical Release 55 (Soil Conservation Service, 1986) and models such as SWMM (Huber & Dickinson, 1988) and STORM (Hydrologic Engineering Center, 1977). The groundwater model has been given a somewhat stronger conceptual basis by limiting the unsaturated zone moisture storage capacity. The graphics outputs have been converted to VGA and color has been used more extensively.

The most significant changes in the manual are an expanded mathematical description of the model (Appendix A) and much more detailed guidance on parameter estimation (Appendix B). Both changes are in response to suggestions by many users. The extra mathematical details are for the benefit of researchers who wish to modify (and improve) GWLF for their own purposes. The new sections on parameter estimation (and the many new tables) are for users who may not be familiar with curve numbers, erosivity coefficients, etc., or who do not have access to some of the primary sources. The general intent has been to make the manual self-contained.

This manual describes the computer software package which can be used to implement GWLF. The associated programs are written in QuickBASIC 4.5 for personal computers using the MS-DOS operating system and VGA graphics. The manual and associated programs (on floppy disk) are available withou charge from the senior author. The programs are distributed in both executable (.EXE) and source code form (.BAS). Associated example data files and outputs for Example 1 and a 30-yr weather set for Walton NY used in Example 3 are also included on the disk.

The main body of this manual describes the program structures and input and output files and options Three examples are also presented. Four appendices present the mathematical structure of GWLF, methods for estimation of model parameters, results of a validation study, and sample listings of input and output files

In this manual, the program name, options in the menu page, and input by the user are written in bold underline and *italic*, respectively.

MODEL DESCRIPTION

Model Structure

The GWLF model includes dissolved and solid-phase nitrogen and phosphorus in streamflow from the sources shown in Figure 1. Rural nutrient loads are transported in runoff water and eroded soil from numerous source areas, each of which is considered uniform with respect to soil and cover. Dissolved loads from each source area are obtained by multiplying runoff by dissolved concentrations. Runoff is computed by using the Soil Conservation Service Curve Number Equation. Solid-phase rural nutrient loads are given by the product of monthly sediment yield and average sediment nutrient concentrations. Erosion is computed using the Universal Soil Loss Equation and the sediment yield is the product of erosion and sediment delivery ratio. The yield in any month is proportional to the total transport capacity of daily runoff during the month. Urban nutrient loads, assumed to be entirely solid-phase, are modeled by exponential accumulation and washoff functions. Septic systems are classified according to four types: normal systems, ponding systems, short-circuiting systems, and direct discharge systems. Nutrient loads from septic systems are calculated by estimating the per capita daily load from each type of system and the number of people in the watershed served by each type. Daily evapotranspiration is given by the product of a cover factor and potential evapotranspiration. The latter is estimated as a function of daylight hours, saturated water vapor pressure and daily temperature.

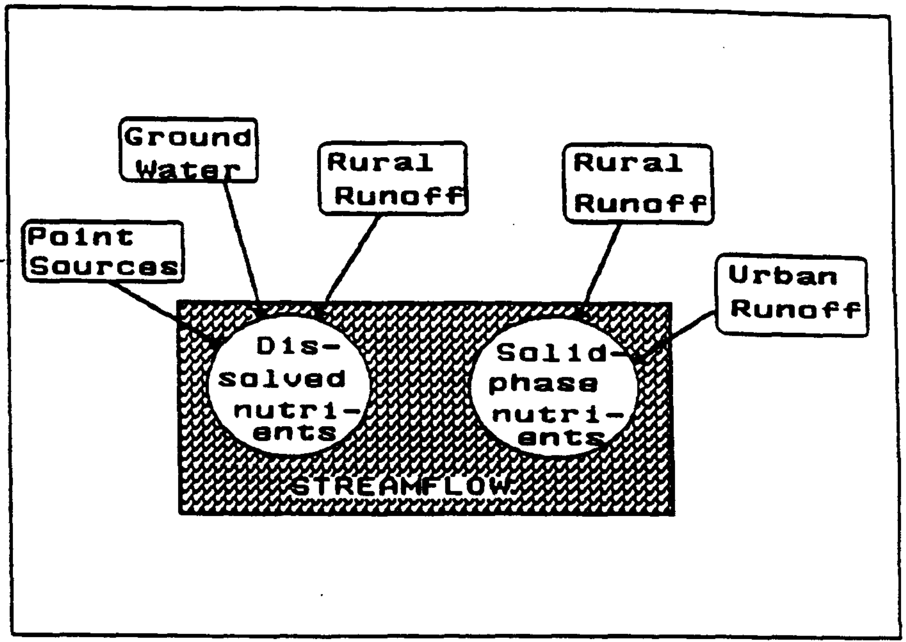


Figure 1. Nutrient Sources in GWLF.

Streamflow consists of runoff and discharge from groundwater. The latter is obtained from a lumped parameter watershed water balance. Daily water balances are calculated for unsaturated and shallow saturated zones. Infiltration to the unsaturated and shallow saturated zones equals the excess, if any, of rainfall and snowmelt less runoff and evapotranspiration. Percolation occurs when unsaturated zone water exceeds field capacity. The shallow saturated zone is modeled as a linear groundwater reservoir.

Model structure, including mathematics, is discussed in more detail in Appendix A.

Input Data

The GWLF model requires daily precipitation and temperature data, runoff sources and transport and chemical parameters. Transport parameters include areas, runoff curve numbers for antecedent moisture condition II and the erosion product K•LS•C•P for each runoff source. Required watershed transport parameters are groundwater recession and seepage coefficients, the available water capacity of the unsaturated zone, the sediment delivery ratio and monthly values for evapotranspiration cover factors, average daylight hours, growing season indicators and rainfall erosivity coefficients. Initial values must also be specified for unsaturated and shallow saturated zones, snow cover and 5-day antecedent rain fall plus snowmelt.

Input nutrient data for rural source areas are dissolved nitrogen and phosphorus concentrations in runoff and solid-phase nutrient concentrations in sediment. If manure is spread during winter months on any rural area, dissolved concentrations in runoff are also specified for each manured area. Daily nutrient accumulation rates are required for each urban land use. Septic systems need estimates of the per capita nutrient load in septic system effluent and per capita nutrient losses due to plant uptake, as well as the number of people served by each type of system. Point sources of nitrogen and phosphorus are assumed to be in dissolved form and must be specified for each month. The remaining nutrient data are dissolved nitrogen and phosphorus concentrations in groundwater.

Procedures for estimating transport and nutrient parameters are described in Appendix B. Examples are given in Appendix C and in subsequent sections of this manual.

Model Output

The GWLF program provides its simulation results in tables as well as in graphs. The following principal variables are given:

Monthly Streamflow
Monthly Watershed Erosion and Sediment Yield
Monthly Total Nitrogen and Phosphorus Loads in Streamflow
Annual Erosion from Each Land Use
Annual Nitrogen and Phosphorus Loads from Each Land Use

The program also provides

Monthly Precipitation and Evapotranspiration
Monthly Ground Water Discharge to Streamflow
Monthly Watershed Runoff
Monthly Dissolved Nitrogen and Phosphorus Loads in Streamflow
Annual Dissolved Nitrogen and Phosphorus Loads from Each Land Use
Annual Dissolved Nitrogen and Phosphorus Loads from Septic Systems

GWLF PROGRAM

Required Files

Simulations by GWLF require four program modules and three data files on the default drive. The three necessary data files are **WEATHER.DAT**, **TRANSPRT.DAT** and **NUTRIENT.DAT**. The four compiled modules, **GWLF20.EXE**, **TRAN20.EXE**, **NUTR20.EXE**, and **OUTP20.EXE** are run by typing *GWLF20*.

Two daily weather files for Walton, NY are included on the disks. **WALT478.382** is the four year (4/78-3/92) record used for model validation and in Examples 1 and 2. **WALT462.392** is the 30 year (4/62- 3/92) record used in Example 3. Prior to running the programs, the appropriate weather record should be copied to **WEATHER.DAT**.

The final two data files on the disks (**RESULTS.DAT**, and **SUMMARY.DAT**) are output files from Example 1. **GWLF20.BAS**, **TRAN20.BAS**, **NUTR20.BAS**, and **OUTP20.BAS** are the uncompiled, QuickBASIC files for the modules, and can be used to modify the existing program.

Program Structure

The structure of GWLF is illustrated in Figure 2. Once the program has been activated, the main control page appears on the screen, as shown in DISPLAY 1. This page is the main menu page that leads to the four major options of the program. The selection of a program option provides access to another set of menu pages within the chosen option. After completing an option, the program returns the user to the main menu page for further actions.

The selection of the menu options is done by typing the number indicating a choice and then *Enter*.

```
Select one of the following :
     1      Create or print TRANSPRT.DAT (Transport parameters)
     2      Create or print NUTRIENT.DAT (nutrient parameters)
              (TRANSPRT.DAT must be created before NUTRIENT.DAT)
     3      Run simulation
     4      Obtain output
     5      Stop (End)
?
```

DISPLAY 1. The Main Menu Page of the GWLF Program.

For example, selection of Run simulation is done by typing *3* and *Enter*.

Transport Data Manipulation

The first step in using the program is to define transport parameters either by creating a new transport data file or modifying an existing one. Options are shown in DISPLAY 2. If the user wishes to create a new transport data file, selection of Create new TRANSPRT.DAT file leads to the input mode. On the other hand, if the user wishes to modify an existing transport data file, selection of Modify existing TRANSPRT.DAT file leads to the modification mode. After input/modification, the user can obtain a hard copy of the transport data by selecting Print TRANSPORT data.

```
Select :
     1      Create new TRANSPRT.DAT file
     2      Modify existing TRANSPRT.DAT file
     3      Print TRANSPORT data
  otherwise Return
?
```

DISPLAY 2. The Menu Page for Manipulation of Transport Parameters.

Create a New TRANSPRT.DAT File. New values of transport parameters are input one by one in this mode. Values are separated by *Enter* keys. After the number of land uses are input, a table is displayed in the screen to help the user to input data. The line in the bottom of the screen provides on-line help which indicates the expected input data type.

In cases when a serious error has been made, the user can always restart this process by hitting *F1*, then *Enter*. Alternatively, the user may save current input and modify the data in the modification mode.

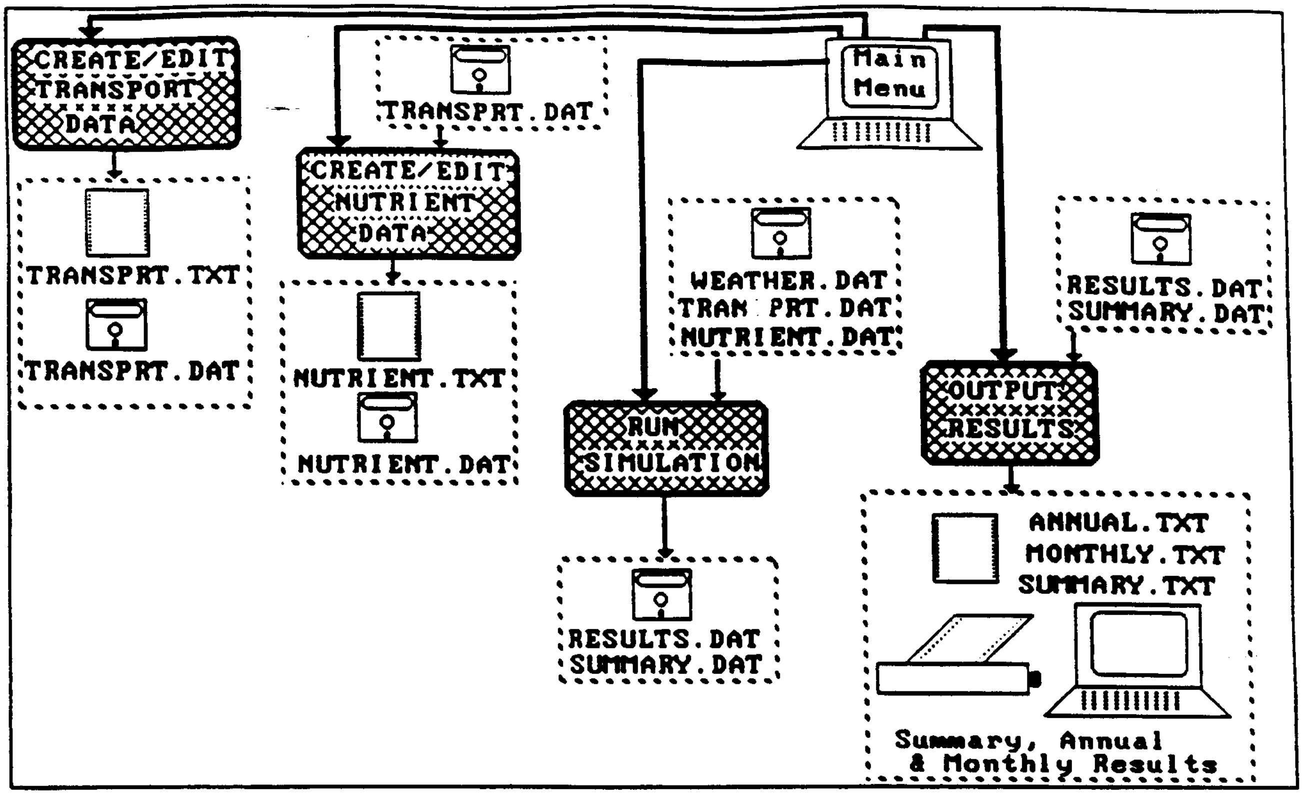


Figure 2. Structure of the GWLF Program.

After all input is complete, the user is asked whether to save or abort the changes. An input of *Y* will overwrite the existing, if any, transport data file.

Modify an Existing TRANSPRT.DAT File. An existing transport data file can be modified in this mode. This is convenient when only minor modification of transport data is needed, e.g., in the case of studying impacts of changes of land use on a watershed.

In this mode, the user is expected to hit *Enter* if no change would be made and *Space bar* if a new value would be issued. The two lines at the bottom of screen provide on-line help.

Print TRANSPORT Data. The user can choose one or more of the three types of print out of transport parameters, namely, to display to screen, print a hard copy, or create a ASCII text file named TRANSPRT.TXT. The text file can later be imported to a word processor to generate reports.

Nutrient Data Manipulation

When nutrient loads are of concern, the nutrient data file (NUTRIENT.DAT) must be available before a simulation can be run. This is done by either creating a new nutrient data file or modifying an existing one. Options are shown in DISPLAY 3. Procedures for creating, modifying or printing nutrient data are similar to those described for the transport data. The ASCII text file is NUTRIENT.TXT.

Simulation

Four categories of simulation can be performed, as shown in DISPLAY 4. To simulate streamflow or sediment yield, two data files, WEATHER.DAT and TRANSPRT.DAT must be in the default directory. An additional data file, NUTRIENT.DAT, is required when nutrient loads are simulated.

```
Select :
      1      Create new NUTRIENT.DAT file
      2      Modify existing NUTRIENT.DAT file
      3      Print NUTRIENT data
      4      Return
?
```

DISPLAY 3. The Menu Page for Manipulation of Nutrient Parameters.

```
Select program options:
      1     Streamflow simulation only
      2     Streamflow and sediment yield only
      3     Streamflow, sediment yield, and nutrient loads
      4     Streamflow, sediment yield, nutrient loads, and septic systems
  otherwise  Return
?
```

DISPLAY 4. The Menu Page for Simulation Options.

After choosing the type of simulation, the user inputs the title of this specific simulation. This title can be a word, a sentence, or a group of words. The user then decides the length, in years, of the simulation run (not to exceed the number of years of weather data in **WEATHER.DAT**).

Results Output

Simulation output can be reported in three categories, namely, overall means, annual values, and monthly values. Either tables or graphs can be generated, as shown in DISPLAY 5. In producing tables, i.e., when one of the first three options is selected, the user can choose to display it on screen, print it on a printer, or save it as an ASCII text file. When one of the graph options is selected, the user is able to see the graph on the screen. If the computer has suitable printer driver, a hard copy of the graph can be obtained by pressing *Shift-PrtSc* keys together.

```
Select :
      1      Print summary
      2      Print annual results
      3      Print monthly results
      4      Graph summary (average)
      5      Graph annual results
      6      Graph monthly results
             (PrtSc for hard copy, carriage return to continue)
  otherwise  Return
?
```

DISPLAY 5. The Menu Page for Output Generation.

EXAMPLE 1: 4-YEAR STUDY IN WEST BRANCH DELAWARE BASIN

This example is designed to allow the user to become familiar with the operation of the program and the way results are presented. The data set and results are those described in Appendix C for the GWLF validation for the West Branch Delaware River Watershed in New York.

The programs **GWLF20.EXE, TRAN20.EXE, NUTR20.EXE,** and **OUTP20.EXE**, and the data files **WEATHER.DAT, TRANSPRT.DAT,** and **NUTRIENT.DAT** must be on the default drive. The weather file can be obtained by copying **WALT478.382** to **WEATHER.DAT**.

Simulation

To start the program, type *GWLF20* then *Enter*. The first screen is the main menu (see DISPLAY 1). To select Run simulation, type *3* and *Enter*. This will lead to the simulation option menu (see DISPLAY 4). Since nutrient fluxes and septic system loads are of interest, type *4* and *Enter*. This will start the simulation.

The user is then asked to input the title of this simulation. Type *Example 1* and *Enter*. Finally the user is expected to specify the length of the simulation. Type *4*, then *Enter*. This concludes the information required for a simulation run. The input section described above is shown in DISPLAY 6.

The screen is now switched to graphic mode. During the computation, part of the result will be displayed. This is to provide a sample of the result and to monitor the progress of the simulation. As shown in Figure 3, the line on the top of the screen reports the length of simulation and the current simulated month/year.

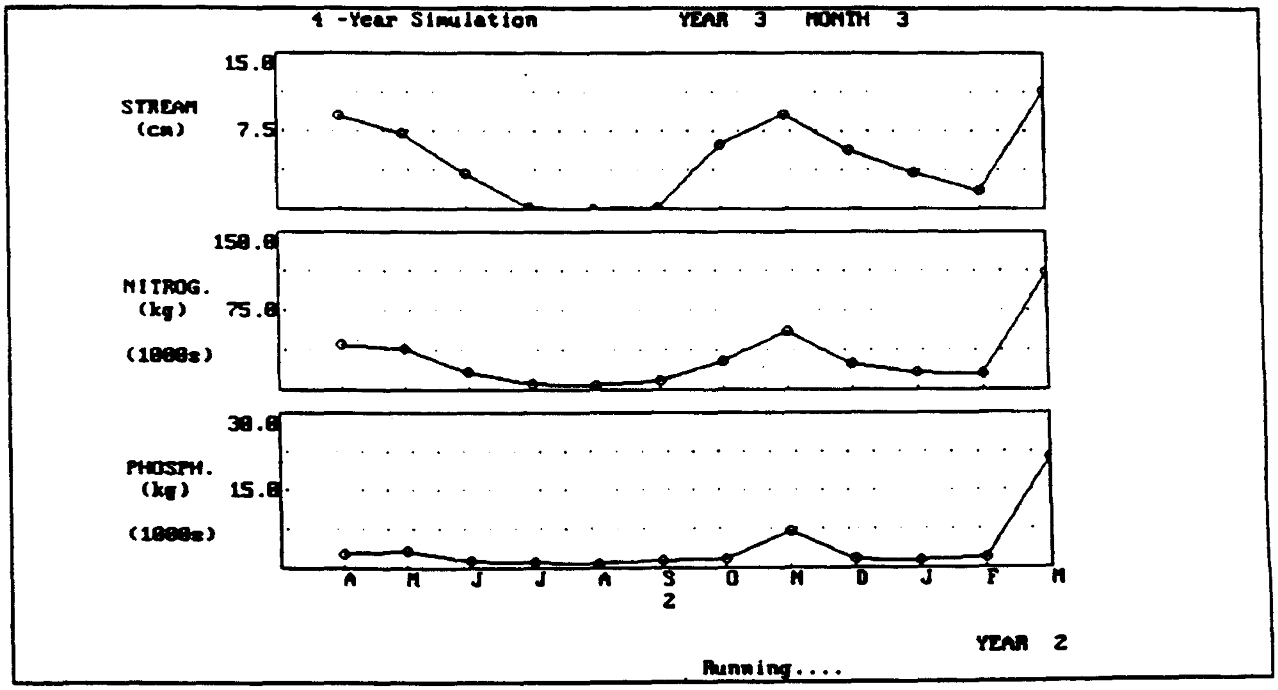


Figure 3. Screen Display during Simulation.

The main menu is displayed at the end of the simulation. From here, the user can generate several types of results.

Results Generation

Type *4*, then *Enter* to generate results. For printing out monthly streamflows, sediment yields, and nutrient loads, type *3*, then *Enter*. The user is asked whether to specify the range of the period to be reported. Type *N*, then *Enter* to select the default full period.

```
Select one of the following :
      1     Create or print TRANSPRT.DAT (Transport parameters)
      2     Create or print NUTRIENT.DAT (nutrient parameters)
              (TRANSPRT.DAT must be created before NUTRIENT.DAT)
      3     Run simulation
      4     Obtain output
      5     Stop (End)
? 3

Select program options:
      1     Streamflow simulation only
      2     Streamflow and sediment yield only
      3     Streamflow, sediment yield, and nutrient loads
      4     Streamflow, sediment yield, nutrient loads, and septic systems
  otherwise Return
? 3

TITLE OF SIMULATION? Example 1
LENGTH OF RUN IN YEARS? 4
```

DISPLAY 6. Input Section in Example 1. User Input is Indicated by Italics.

The user decides on the type of output. Type *1*, then *Enter* to print to the screen. The result is displayed in nine screens. After reading a screen, press *Enter* to bring up the next screen. To generate a hard copy, turn on the printer, type *2* and *Enter*. Alternatively, the user can save the result in a text file, **MONTHLY.TXT**. The user can go back to the previous page menu to select another option of results generation by pressing *Enter*. Part of the process described above is shown in DISPLAY 7. To generate graphs of the monthly results, type *6* and *Enter*. This produces graphs such as Figure 4 and Figure 5. The user can call up the main menu again by pressing *Enter* keys. The data input files **TRANSPRT.DAT**, **NUTRIENT.DAT** and **WEATHER.DAT** for this example are listed in Appendix E with the various .TXT files that may be generated.

EXAMPLE 2: EFFECTS OF ELIMINATION OF WINTER MANURE SPREADING

In this example, nutrient parameters are modified to investigate effects of winter manure applications. The example involves manipulation of the data file **NUTRIENT.DAT**. If the user wishes to save the original file, it should first be copied to a new file, say **NUTRIENT.EX1**.

Nutrient Parameters Modification

From the main menu, type *2*, *Enter*. This leads to the nutrient data manipulation option. Type *2*, *Enter* to modify **NUTRIENT.DAT** (see DISPLAY 8).

Type *Enter* to accept the original dissolved nutrient concentrations. Repeat this procedure until the cursor is in the line, Number of Land Uses on Which Manure is Spread (see DISPLAY 9), hit *Space-bar*, type *0*, and hit *Enter*.

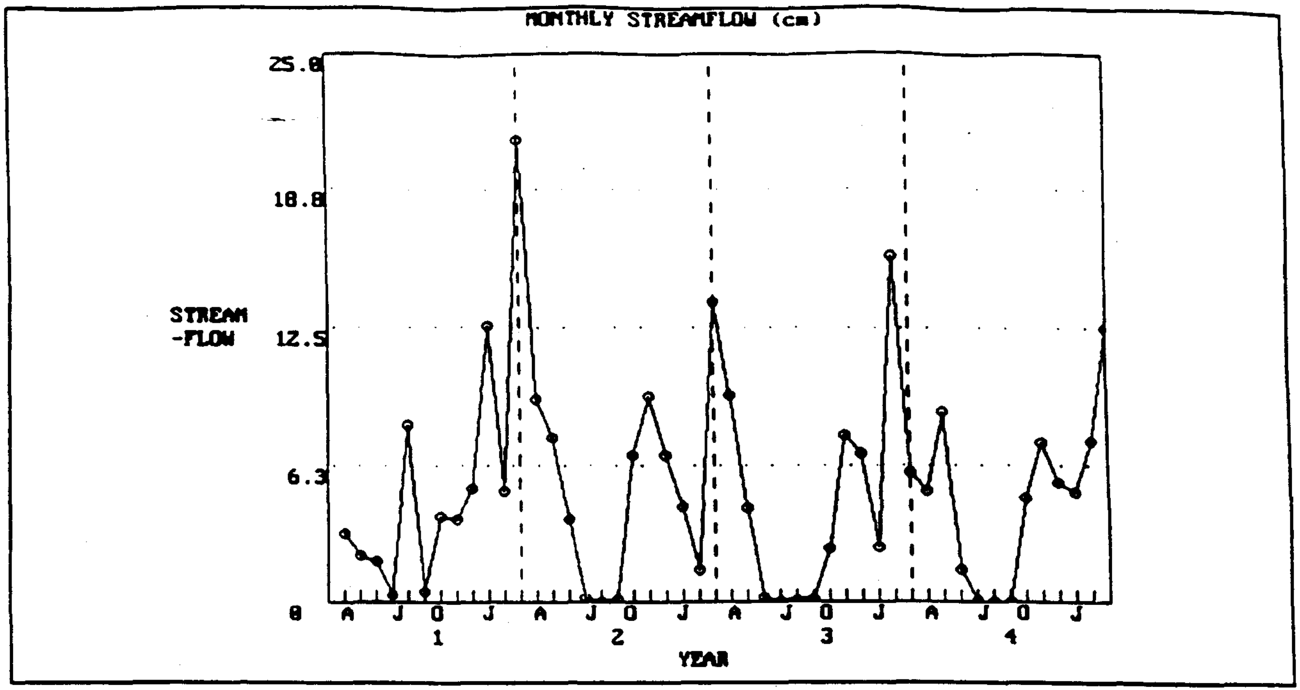


Figure 4. Monthly Streamflows for Example 1.

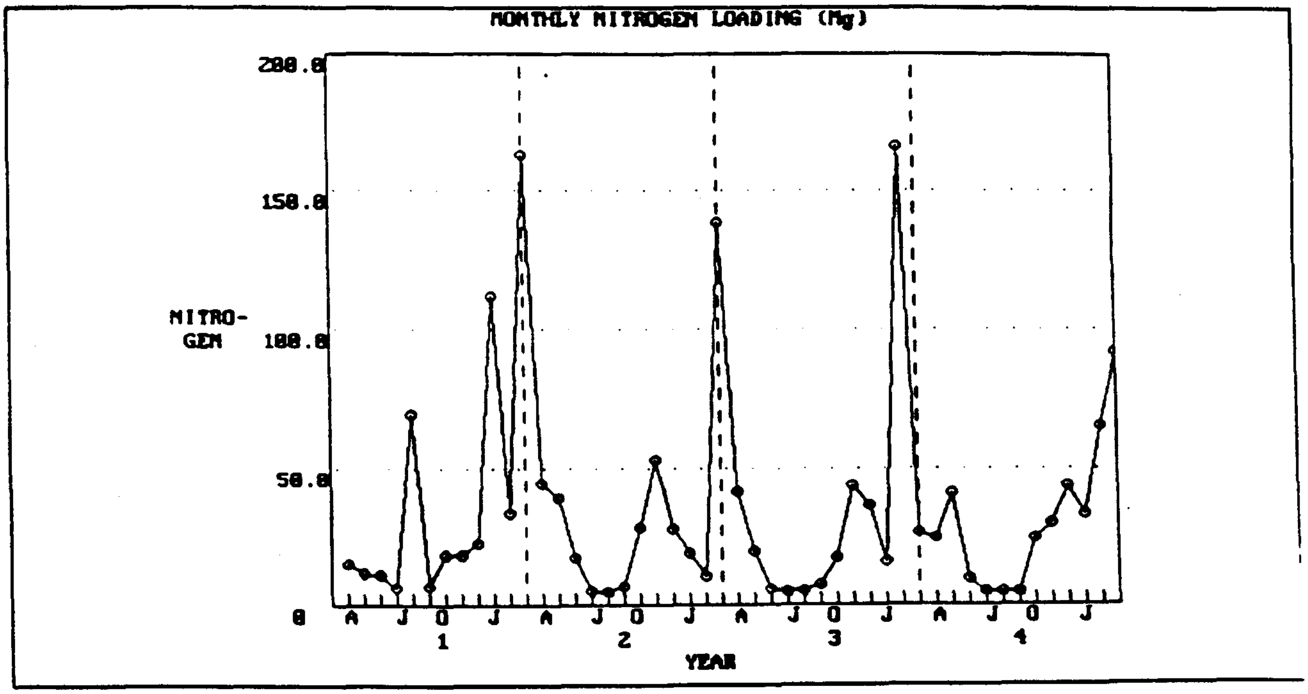


Figure 5. Monthly Nitrogen Loads for Example 1.

Accept all the rest of original data by hitting *Enter* key until the end of the file. Type *Y* to save the changes. This concludes the modification of **NUTRIENT.DAT**.

The user may print out nutrient data to make sure these changes have been made. To do so, the user selects Print NUTRIENT data in the nutrient data manipulation page (see DISPLAY 3). Then select Print to screen to display the current nutrient parameters.

```
Select one of the following :
      1       Create or print TRANSPRT.DAT (Transport parameters)
      2       Create or print NUTRIENT.DAT (nutrient parameters)
                (TRANSPRT.DAT must be created before NUTRIENT.DAT)
      3       Run simulation
      4       Obtain output
      5       Stop (End)
? 4

Select :
      1       Print summary
      2       Print annual results
      3       Print monthly results
      4       Graph summary (average)
      5       Graph annual results
      6       Graph monthly results
              (PrtSc for hard copy, carriage return to continue)
  otherwise   Return
? 3
      Want to specify the range of years in output?   ( Type  Y  or  N )
? N

Select : (For printing MONTHLY data)
      1       Print to screen (carriage return to continue)
      2       Print a hard copy (turn on printer first)
      3       Print to a file named MONTHLY.TXT
  otherwise   Return
? 1
```

DISPLAY 7. Result Generating Menu in Example 1.

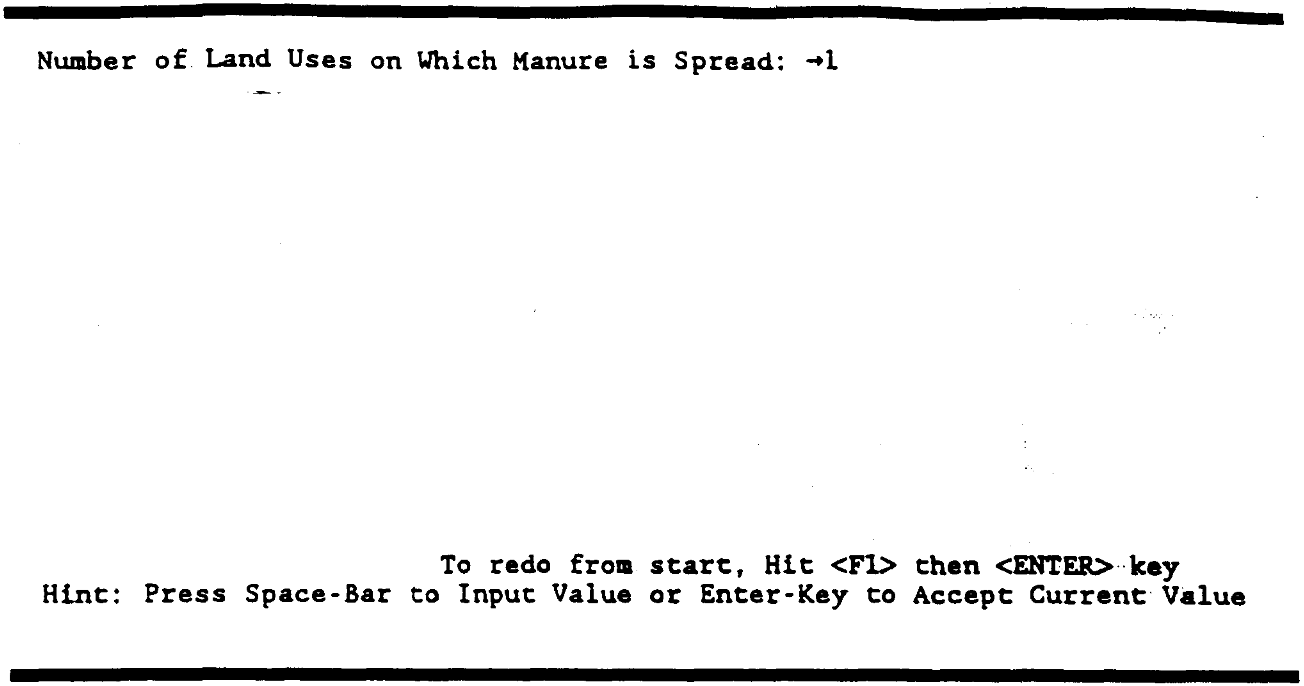
```
Select one of the following :
      1       Create or print TRANSPRT.DAT (Transport parameters)
      2       Create or print NUTRIENT.DAT (nutrient parameters)
                (TRANSPRT.DAT must be created before NUTRIENT.DAT)
      3       Run simulation
      4       Obtain output
      5       Stop (End)
? 2

Select :
      1       Create new NUTRIENT.DAT file
      2       Modify existing NUTRIENT.DAT file
      3       Print NUTRIENT data
  otherwise   Return
? 2
```

DISPLAY 8. Modification of Nutrient Parameters.

Simulation and Results Generation

Following the procedures described in Example 1, the results of a 3-year simulation are shown in Figure 6.



```
Number of Land Uses on Which Manure is Spread: →1




                         To redo from start, Hit <F1> then <ENTER> key
Hint: Press Space-Bar to Input Value or Enter-Key to Accept Current Value
```

DISPLAY 9. The First Screen for Modifying Nutrient Parameters. The Original Number is 1. Hit the *Space Bar*, Type *0*, and then Hit *Enter* Key to Change this Number to 0.

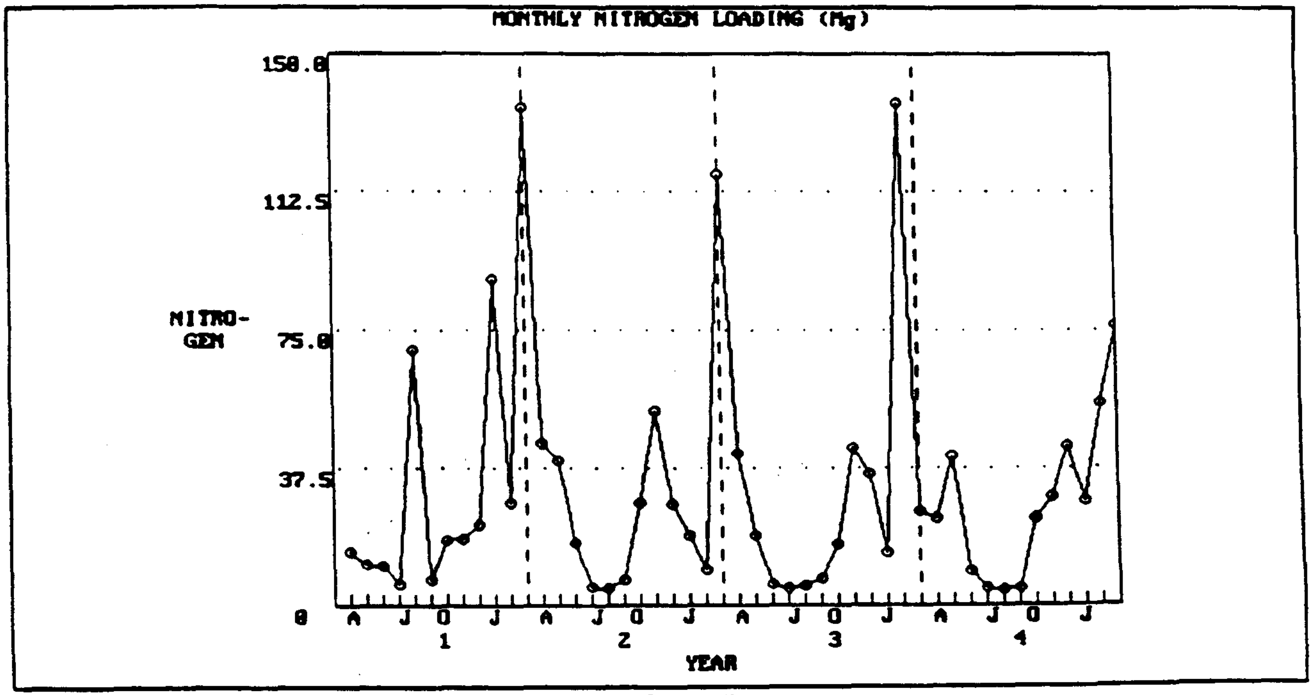


Figure 6. Monthly Nitrogen Loads with no Manure Spreading.

EXAMPLE 3: A 30-YEAR SIMULATION STUDY

In Example 3, a simulation of the West Branch Delaware River Basin is based on a 30-yr (4/62-3/92) weather record given in the file WALT462.392.

Simulation and Results Generation

The simulation is run by following procedures as in Example 1 (see DISPLAY 6). Answer LENGTH OF RUN IN YEARS by typing *30* and then *Enter.* A 30-year simulation takes roughly 8 minutes on an 386 machine with math co-processor.

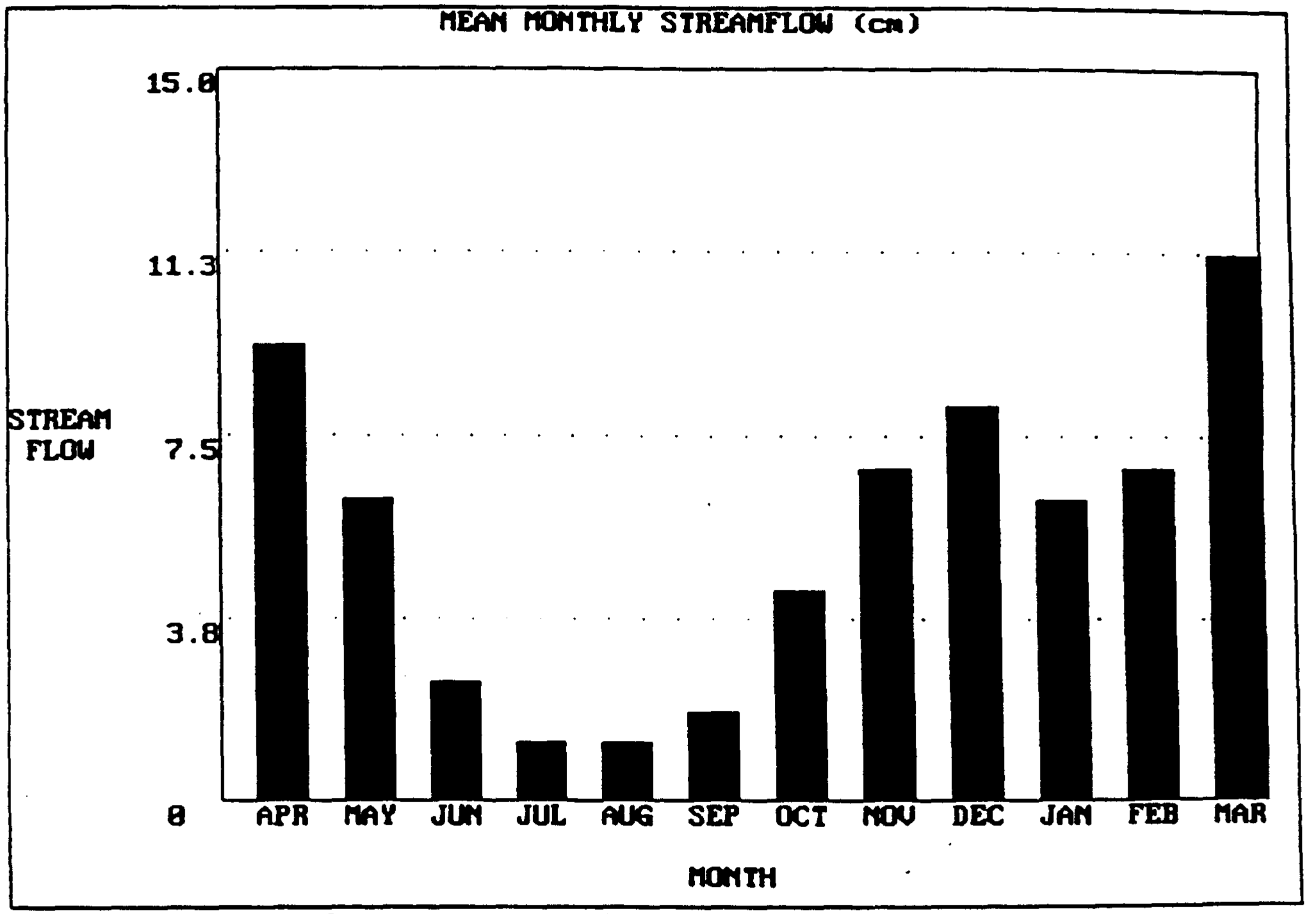


Figure 7. Mean Monthly Streamflows for 30-yr Simulation.

At the end of the computation, the main menu is displayed. From here, the user can generate several types of results by typing *4*, then *Enter*. For a summary of the results, type *1* and *Enter*. To display the summary in screen, type *1* and *Enter*. The summary is displayed in three screens. After reading a screen, press *Enter* to bring up next screen. To generate a hard copy from the printer, turn on the printer, select Print a hard copy. Hit *Enter* to obtain the output option menu.

From the output generation menu (see DISPLAY 5), to obtain a graphical description of the summary, type *4* and then *Enter*. This brings up a screen of options (see DISPLAY 10). Eighteen types of graphs can be generated. For example, to investigate the relative magnitudes of average monthly streamflow, type *5* and *Enter*. This produces the bar chart shown in Figure 7. Similarly, to investigate the nitrogen loads from

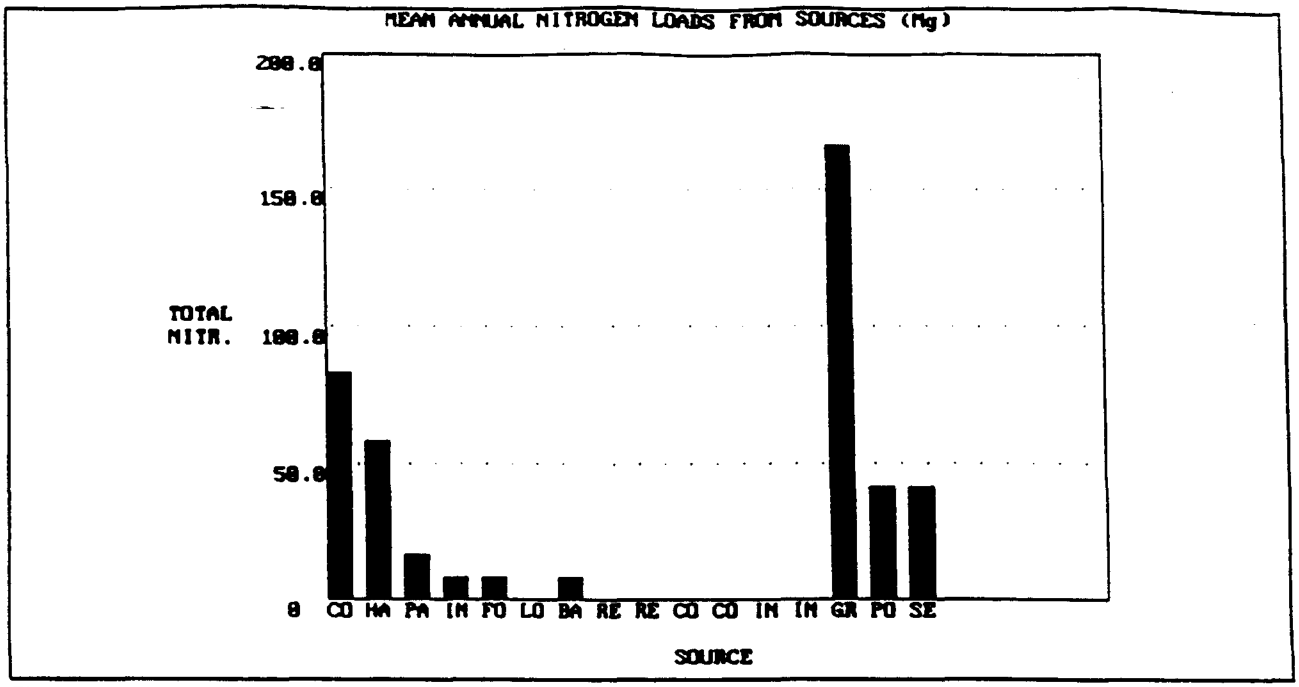


Figure 8. Mean Annual Nitrogen Load from Sources for 30-yr Simulation.

```
Select :
    1     Mean Monthly Precipitation
    2     Mean Monthly Evapotranspiration
    3     Mean Monthly Groundwater Flow
    4     Mean Monthly Runoff
    5     Mean Monthly Streamflow
    6     Mean Monthly Erosion
    7     Mean Monthly Sediment
    8     Mean Monthly Dissolved Nitrogen
    9     Mean Monthly Total Nitrogen
   10     Mean Monthly Dissolved Phosphorus
   11     Mean Monthly Total Phosphorus
   12     Mean Annual Runoff from Sources
   13     Mean Annual Erosion from Sources
   14     Mean Annual Dissolved Nitrogen Loads from Sources
   15     Mean Annual Total Nitrogen Loads from Sources
   16     Mean Annual Dissolved Phosphorus Loads from Sources
   17     Mean Annual Total Phosphorus Loads from Sources
   18     Areas of Sources
 otherwise Return
 ?
```

DISPLAY 10. The Options for Plotting Summary

each source, type *15* and then *Enter*. This generates another bar chart as shown in Figure 8.

For plotting annual streamflows, sediment yields and nutrient loads, type *5*, then *Enter*. The graphs will be displayed on several screens. For example, Figure 9 shows the predicted annual streamflows.

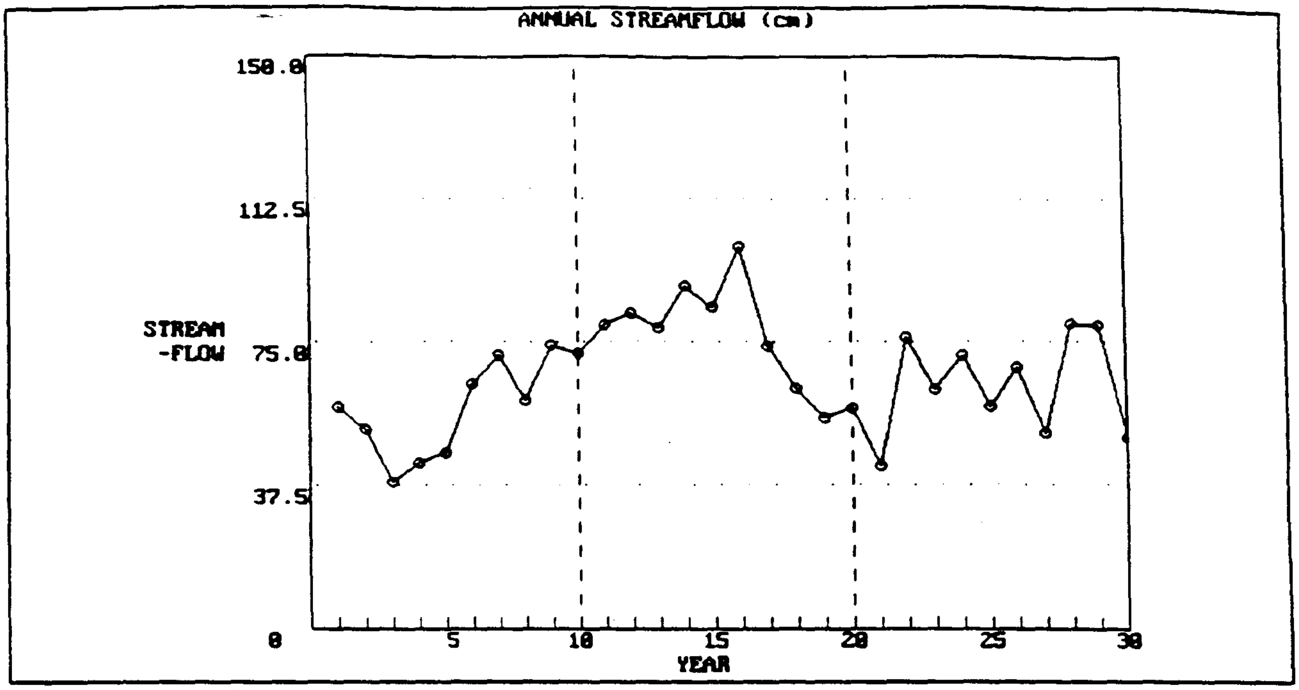


Figure 9. Annual Streamflows for 30-yr Simulation.

APPENDIX A: MATHEMATICAL DESCRIPTION OF GWLF

General Structure

Streamflow nutrient flux contains dissolved and solid phases. Dissolved nutrients are associated with runoff, point sources and groundwater discharges to the stream. Solid-phase nutrients are due to point sources, rural soil erosion or wash off of material from urban surfaces. The GWLF model describes nonpoint sources with a distributed model for runoff, erosion and urban wash off, and a lumped parameter linear reservoir groundwater model. Point sources are added as constant mass loads which are assumed known. Water balances are computed from daily weather data but flow routing is not considered. Hence, daily values are summed to provide monthly estimates of streamflow, sediment and nutrient fluxes (it is assumed that streamflow travel times are much less than one month).

Monthly loads of nitrogen or phosphorus in streamflow in any year are

$$LD_m = DP_m + DR_m + DG_m + DS_m \qquad \text{(A-1)}$$

$$LS_m = SP_m + SR_m + SU_m \qquad \text{(A-2)}$$

In these equations, LD_m is dissolved nutrient load, LS_m is solid-phase nutrient load, DP_m, DR_m, DG_m and DS_m are point source, rural runoff, groundwater and septic system dissolved nutrient loads, respectively, and SP_m, SR_m and SU_m and are solid-phase point source, rural runoff and urban runoff nutrient loads (kg), respectively, in month m (m = 1,2,...12). Note that the equations assume (i) point source, groundwater and septic system loads are entirely dissolved; and (ii) urban nutrient loads are entirely solid.

Rural Runoff Loads

Rural nutrient loads are transported in runoff water and eroded soil from numerous source areas, each of which is considered uniform with respect to soil and cover.

Dissolved Loads. Dissolved loads from each source area are obtained by multiplying runoff by dissolved concentrations. Monthly loads for the watershed are obtained by summing daily loads over all source areas:

$$LD_m = 0.1 \sum_k \sum_{t=1}^{d_m} Cd_k \, Q_{kt} \, AR_k \qquad \text{(A-3)}$$

where Cd_k = nutrient concentration in runoff from source area k (mg/l), Q_{kt} = runoff from source area k on day t (cm) and AR_k = area of source area k (ha) and d_m = number of days in month m.

Runoff is computed from daily weather data by the U.S. Soil Conservation Service's Curve Number Equation (Ogrosky & Mockus, 1964):

$$Q_{kt} = \frac{(R_t + M_t - 0.2\, DS_{kt})^2}{R_t + M_t + \underset{0.8}{\cancel{0.2}}\, DS_{kt}} \qquad \text{(A-4)}$$

Rainfall R_t (cm) and snowmelt M_t (cm of water) on day t are estimated from daily precipitation and temperature data. Precipitation is assumed to be rain when daily mean air temperature T_t (°C) is above 0 and snow fall otherwise. Snowmelt water is computed by a degree-day equation (Haith, 1985):

$$M_t = 0.45\, T_t, \qquad \text{for } T_t > 0 \qquad \text{(A-5)}$$

The detention parameter DS_{kt} (cm) is determined from a curve number CN_{kt} as

$$DS_{kt} = \frac{2540}{CN_{kt}} - 25.4 \qquad \text{(A-6)}$$

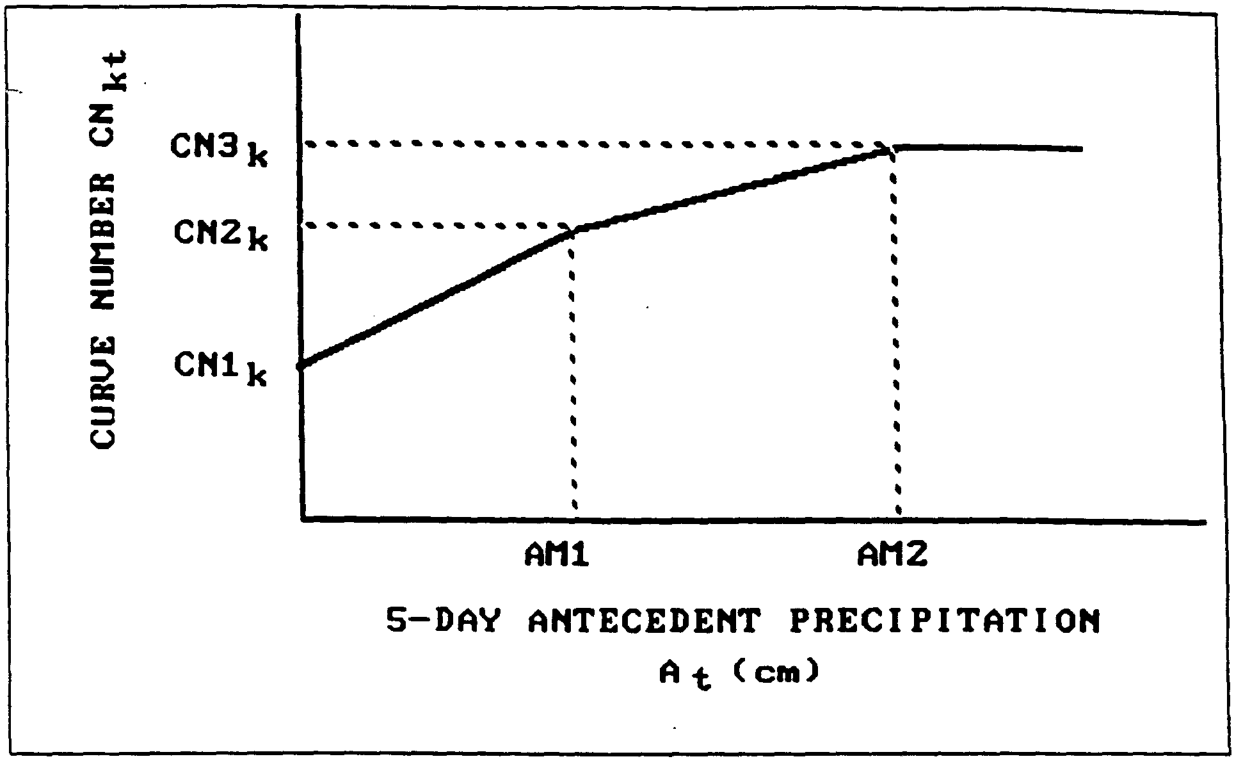


Figure A-1. Curve Number Selection as Function of Antecedent Moisture.

Curve numbers are selected as functions of antecedent moisture as described in Haith (1985), and shown in Figure A-1. Curve numbers for antecedent moisture conditions 1 (driest), 2 (average) and 3 (wettest) are $CN1_k$, $CN2_k$ and $CN3_k$ respectively. The actual curve number for day t, CN_{kt}, is selected as a linear function of A_t, 5-day antecedent precipitation (cm):

$$A_t = \sum_{n=t-5}^{t-1} (R_n + M_n) \qquad \text{(A-7)}$$

Recommended values (Ogrosky & Mockus, 1964) for the break points in Figure A-1 are AM1 = 1.3, 3.6 cm, and AM2 = 2.8, 5.3 cm, for dormant and growing seasons, respectively. For snowmelt conditions, it is assumed that the wettest antecedent moisture conditions prevail and hence regardless of A_t, $CN_{kt} = CN3_k$ when $M_t > 0$.

The model requires specification of $CN2_k$. Values for $CN1_k$ and $CN3_k$ are computed from Hawkins (1978) approximations:

$$CN1_k = \frac{CN2_k}{2.334 - 0.01334\ CN2_k} \qquad \text{(A-8)}$$

$$CN3_k = \frac{CN2_k}{0.4036 + 0.0059\ CN2_k} \qquad \text{(A-9)}$$

Solid-Phase Loads. Solid-phase rural nutrient loads (SR_m) are given by the product of monthly watershed sediment yields (Y_m, Mg) and average sediment nutrient concentrations (c_s, mg/kg):

$$SR_m = 0.001\ c_s\ Y_m \qquad \text{(A-10)}$$

Monthly sediment yields are determined from the model developed by Haith (1985). The model is based on three principal assumptions: (i) sediment originates from sheet and rill erosion (gully and stream bank erosion are neglected); (ii) sediment transport capacity is proportional to runoff to the 5/3 power (Meyer & Wischmeier, 1969); and (iii) sediment yields are produced from soil which erodes in the current year (no carryover of sediment supply from one year to the next).

Erosion from source area k on day t (Mg) is given by

$$X_{kt} = 0.132\ RE_t\ K_k\ (LS)_k\ C_k\ P_k\ AR_k \qquad \text{(A-11)}$$

in which K_k, $(LS)_k$, C_k and P_k are the standard values for soil erodibility, topographic, cover and management and supporting practice factors as specified for the Universal Soil Loss Equation (Wischmeier & Smith, 1978). RE_t is the rainfall erosivity on day t (MJ-mm/ha-h). The constant 0.132 is a dimensional conversion factor associated with the SI units of rainfall erosivity. Erosivity can be estimated by the deterministic portion of the empirical equation developed by Richardson *et al*. (1983) and subsequently tested by Haith & Merrill (1987):

$$RE_t = 64.6\ a_t\ R_t^{1.81} \qquad \text{(A-12)}$$

where the coefficient a_t varies with season and geographical location.

The total watershed sediment supply generated in month j (Mg) is

$$SX_j = DR \sum_k \sum_{t=1}^{d_j} X_{kt} \qquad \text{(A-13)}$$

where DR is the watershed sediment delivery ratio. The transport of this sediment from the watershed is based on the transport capacity of runoff during that month. A transport factor TR_j is defined as

$$TR_j = \sum_{t=1}^{d_j} Q_t^{5/3} \qquad \text{(A-14)}$$

The sediment supply SX_j is allocated to months j, j + 1, ..., 12 in proportion to the transport capacity fo each month. The total transport capacity for months j, j + 1, ..., 12 is proportional to B_j, where

$$B_j = \sum_{h=j}^{12} TR_h \qquad \text{(A-15)}$$

For each month m, the fraction of available sediment X_j which contributes to Y_m, the monthly sedimen yield (Mg), is TR_m/B_j. The total monthly yield is the sum of all contributions from preceding months:

$$Y_m = TR_m \sum_{j=1}^{m} (X_j/B_j) \qquad \text{(A-16)}$$

Urban Runoff

The urban runoff model is based on general accumulation and wash off relationships proposed by Amy et al. (1974) and Sartor & Boyd (1972). The exponential accumulation function was subsequently used in SWMM (Huber & Dickinson, 1988) and the wash off function is used in both SWMM and STORM (Hydrologic Engineering Center, 1977). The mathematical development here follows that of Overton and Meadows (1976).

Nutrients accumulate on urban surfaces over time and are washed off by runoff events. Runoff volumes are computed by equations A-4 through A-7.

If $N_k(t)$ is the accumulated nutrient load on source area (land use) k on day t (kg/ha), then the rate of accumulation during dry periods is

$$\frac{dN_k}{dt} = n_k - \beta N_k \qquad \text{(A-17)}$$

where n_k is a constant accumulation rate (kg/ha-day) and β is a depletion rate constant (day^{-1}). Solving equation A-17, we obtain

$$N_k(t) = N_{k0}\, e^{-\beta t} + (n_k/\beta)\,(1 - e^{-\beta t}) \qquad \text{(A-18)}$$

in which $N_{k0} = N_k(t)$ at time $t = 0$.

Equation A-18 approaches an asymptotic value $N_{k,max}$:

$$N_{k,max} = \lim_{t \to \infty} N_k(t) = n_k/\beta \qquad \text{(A-19)}$$

Data given in Sartor & Boyd (1972) and shown in Figure A-2 indicates that $N_k(t)$ approaches its maximum value in approximately 12 days. If we conservatively assume that $N_k(t)$ reaches 90% of $N_{k,max}$ in 20 days, then for $N_{k0} = 0$,

$$0.90\,(n_k/\beta) = (n_k/\beta)\,(1 - e^{-20\beta}),\ \text{or}\ \beta = 0.12$$

Equation A-18 can also be written for a time interval $\Delta t = t_2 - t_1$ as

$$N_k(t_2) = N_k(t_1)\, e^{-0.12\Delta t} + (n_k/0.12)\,(1 - e^{-0.12\Delta t}) \qquad \text{(A-20)}$$

or, for a time interval of one day,

$$N_{k,t+1} = N_{kt}\, e^{-0.12} + (n_k/0.12)\,(1 - e^{-0.12}) \qquad \text{(A-21)}$$

where N_{kt} is the nutrient accumulation at the beginning of day t (kg/ha).

Equation A-21 can be modified to include the effects of wash off:

$$N_{k,t+1} = N_{kt}\, e^{-0.12} + (n_k/0.12)\,(1 - e^{-0.12}) - W_{kt} \qquad \text{(A-22)}$$

in which W_{kt} = runoff nutrient load from land use k on day t(kg/ha).

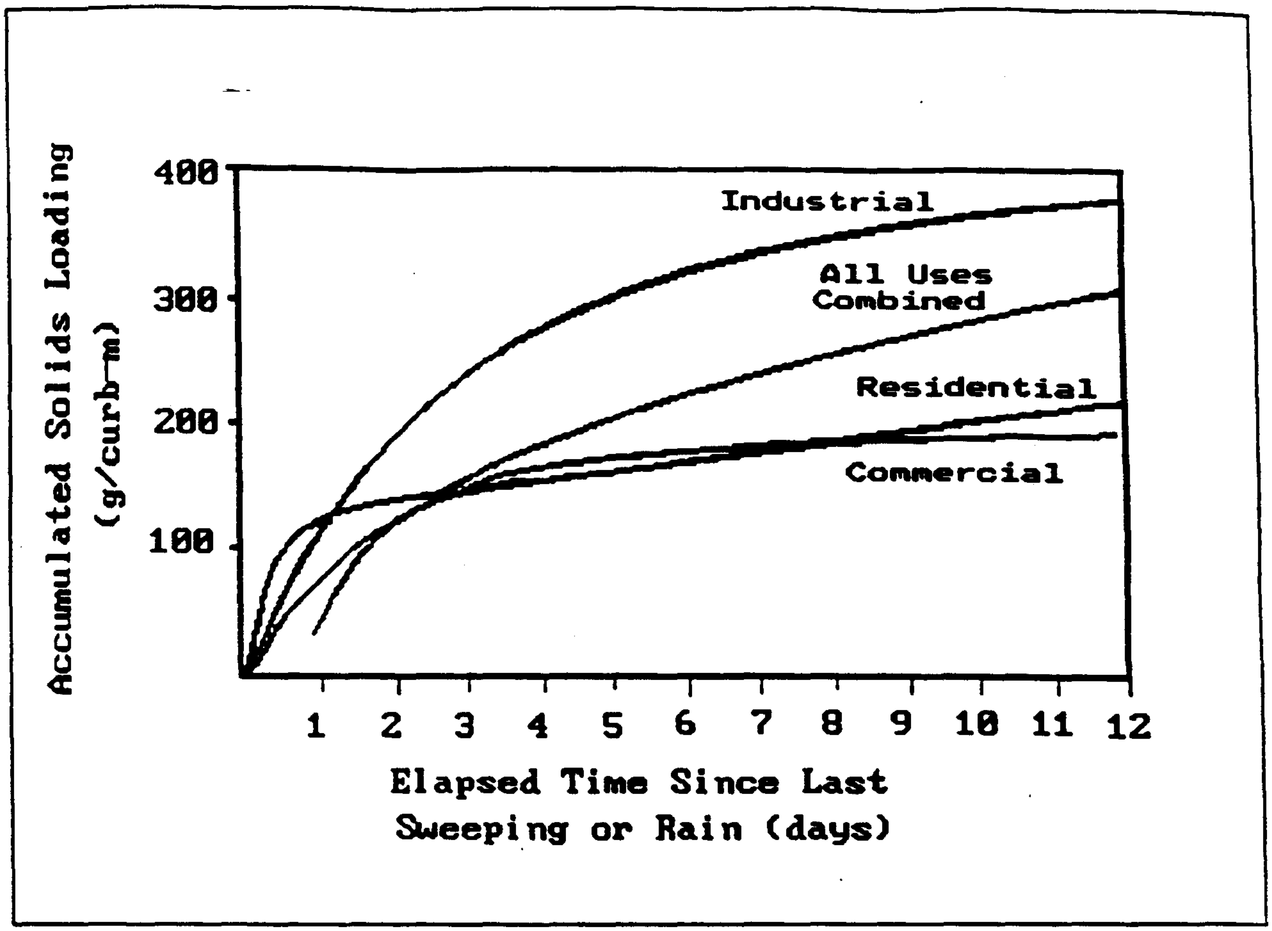


Figure A-2. Accumulation of Pollutants on Urban Surfaces (Sartor & Boyd, 1972; redrawn in Novotny & Chesters, 1981).

The runoff load is

$$W_{kt} = w_{kt} [N_{kt} e^{-0.12} + (n_k/0.12)(1 - e^{-0.12})] \qquad \text{(A-23)}$$

where w_{kt} is the first-order wash off function suggested by Amy et al. (1974):

$$w_{kt} = 1 - e^{-1.81Q_{kt}} \qquad \text{(A-24)}$$

Equation A-24 is based on the assumption that 1.27 cm (0.5 in) of runoff will wash off 90% of accumulated pollutants. Monthly runoff loads of urban nutrients are thus given by

$$SU_m = \cancel{0.1} \sum_{k} \sum_{t=1}^{d_m} W_{kt} AR_k \qquad \text{(A-25)}$$

Groundwater Sources

The monthly groundwater nutrient load to the stream is

$$DG_m = 0.1\, C_g AT \sum_{t=1}^{d_m} G_t \qquad \text{(A-26)}$$

in which C_g = nutrient concentration in groundwater (mg/l), AT = watershed area (ha), and G_t = groundwater discharge to the stream on day t (cm).

Groundwater discharge is described by the lumped parameter model shown in Figure A-3. Streamflow consists of total watershed runoff from all source areas plus groundwater discharge from a shallow saturated zone. The division of soil moisture into unsaturated, shallow saturated ano deep saturated zones is similar to that used by Haan (1972).

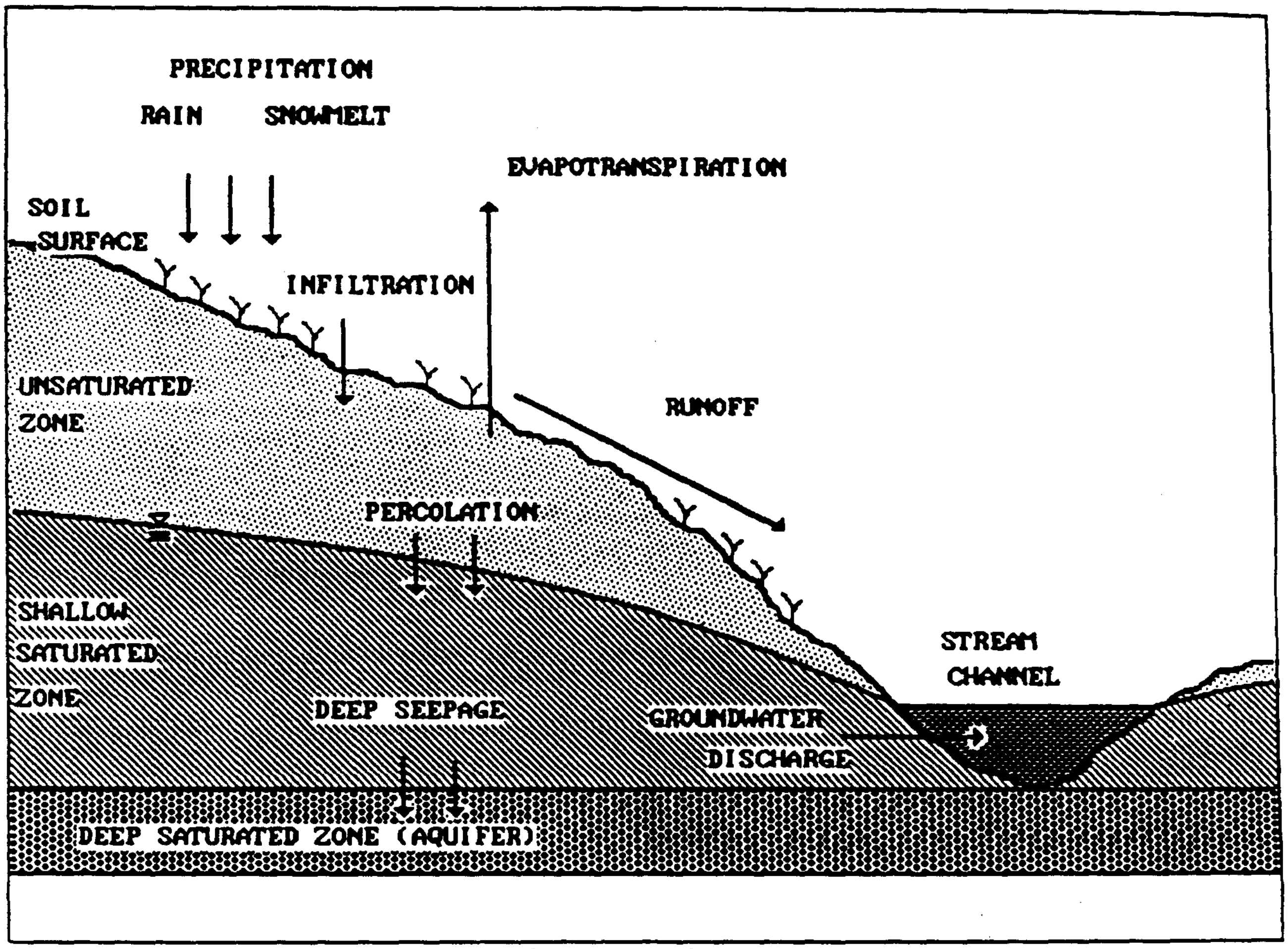


Figure A-3. Lumped Parameter Model for Groundwater Discharge.

Daily water balances for the unsaturated and shallow saturated zones are

$$U_{t+1} = U_t + R_t + M_t - Q_t - E_t - PC_t \tag{A-27}$$

$$S_{t+1} = S_t + PC_t - G_t - D_t \tag{A-28}$$

In these equations, U_t and S_t are the unsaturated and shallow saturated zone soil moistures at the beginning of day t and Q_t, E_t, PC_t, G_t and D_t are watershed runoff, evapotranspiration, percolation into the shallow saturated zone, groundwater discharge to the stream and seepage flow to the deep saturated zone, respectively, on day t (cm).

Percolation occurs when unsaturated zone water exceeds available soil water capacity U^* (cm):

$$PC_t = \text{Max}\ (0;\ U_t + R_t + M_t - Q_t - E_t - U^*) \qquad \text{(A-29)}$$

Evapotranspiration is limited by available moisture in the unsaturated zone:

$$E_t = \text{Min}\ (CV_t\ PE_t;\ U_t + R_t + M_t - Q_t) \qquad \text{(A-30)}$$

for which CV_t is a cover coefficient and PE_t is potential evapotranspiration (cm) as given by Hamon (1961):

$$PE_t = \frac{0.021\ H_t^2\ e_t)}{T_t + 273} \qquad \text{(A-31)}$$

In this equation, H_t is the number of daylight hours per day during the month containing day t, e_t is the saturated water vapor pressure in millibars on day t and T_t is the temperature on day t (°C). When $T_t \leq 0$, PE_t is set to zero. Saturated vapor pressure can be approximated as in (Bosen, 1960):

$$\begin{aligned} e_t = \ & 33.8639\ [\ (0.00738\ T_t + 0.8072)^8 \\ & - 0.000019\ (1.8\ T_t + 48) + 0.001316\ ]\ , \qquad T_t \geq 0 \end{aligned} \qquad \text{(A-32)}$$

As in Haan (1972), the shallow unsaturated zone is modeled as a simple linear reservoir. Groundwater discharge and deep seepage are

$$G_t = r\ S_t \qquad \text{(A-33)}$$

and

$$D_t = s\ S_t \qquad \text{(A-34)}$$

where r and s are groundwater recession and seepage constants, respectively (day^{-1}).

Septic (On-site Wastewater Disposal) Systems

The septic system component of GWLF is based on the model developed by Mandel (1993). For purposes of assessing watershed water quality impacts, septic systems loads can be divided into four types:

$$DS_m = DS_{1m} + DS_{2m} + DS_{3m} + DS_{4m} \qquad \text{(A-35)}$$

where DS_{1m}, DS_{2m}, DS_{3m} and DS_{4m} are the dissolved nutrient load to streamflow from normal, short-circuited, ponded and direct discharge systems, respectively in month m (kg). These loads are computed from per capita daily effluent loads and monthly populations served a_{jm} for each system (j = 1,2,3,4).

Normal Systems. A normal septic system is a system whose construction and operation conforms to recommended procedures such as those suggested by the EPA design manual for on-site wastewater disposal systems (U. S. Environmental Protection Agency, 1980). Effluents from such systems infiltrate into the soil and enter the shallow saturated zone. Effluent nitrogen is converted to nitrate, and except for removal by plant uptake, the nitrogen is transported to the stream by groundwater discharge. Conversely, phosphates in the effluent are adsorbed and retained by the soil and hence normal systems provide no phosphorus loads to streamflow. The nitrogen load to groundwater from normal systems in month m (kg) is

$$SL_{1m} = 0.001\ a_{1m}\ d_m\ (e - u_m) \qquad \text{(A-36)}$$

in which e = per capita daily nutrient load in septic tank effluent (g/day) and u_m = per capita daily nutrient uptake by plants in month m (g/day).

Normal systems are generally some distance from streams and their effluent mixes with other groundwater. Monthly nutrient loads are thus proportional to groundwater discharge to the stream. The portion of the annual load delivered in month m is equivalent to the portion of annual groundwater discharge which occurs in that month. Thus the load in month m of any year is

$$DS_{1m} = \frac{GR_m \sum_{m=1}^{12} \cancel{a_{1m}}\, SL_{1m}}{\sum_{m=1}^{12} GR_m} \qquad \text{(A-37)}$$

where GR_m = total groundwater discharge to streamflow in month m (cm), obtained by summing the daily values G_t for the month. Equation A-37 applies only for nitrogen. In the case of phosphorus, $DS_{1m} = 0$.

Short-Circuited Systems. These systems are located close enough to surface waters (~ 15 m) so that negligible adsorption of phosphorus takes place. The only nutrient removal mechanism is plant uptake, and the watershed load for both nitrogen and phosphorus is

$$DS_{2m} = 0.001\ a_{2m}\ d_m\ (e - u_m) \qquad \text{(A-38)}$$

Ponded Systems. These systems exhibit hydraulic failure of the tank's absorption field and resulting surfacing of the effluent. Unless the surfaced effluent freezes, ponding systems deliver their nutrient loads to surface waters in the same month that they are generated through overland flow. If the temperature is below freezing, the surfacing effluent is assumed to freeze in a thin layer at the ground surface. The accumulated frozen effluent melts when the snowpack disappears and the temperature is above freezing. The monthly nutrient load is

$$DS_{3m} = 0.001 \sum_{t=1}^{d_m} PN_t \qquad \text{(A-39)}$$

where PN_t = watershed nutrient load in runoff from ponded systems on day t (g). Nutrient accumulation under freezing conditions is

$$FN_{t+1} = \begin{cases} FN_t + a_{3m}\, e\ , & SN_t > 0 \text{ or } T_t \le 0 \\ 0 & , \text{ otherwise} \end{cases} \qquad \text{(A-40)}$$

where FN_t = frozen nutrient accumulation in ponded systems at the beginning of day t (g). The runoff load is thus

$$PN_t = \begin{cases} a_{3m}\, e + FN_t - u_m\ , & SN_t = 0 \text{ and } T_t > 0 \\ 0 & , \text{ otherwise} \end{cases} \qquad \text{(A-41)}$$

Direct Discharge Systems. These illegal systems discharge septic tank effluent directly into surface waters. Thus,

$$DS_{4m} = 0.001\ a_{4m}\ d_m\ e \qquad \text{(A-42)}$$

APPENDIX B: DATA SOURCES & PARAMETER ESTIMATION

Four types of information must be assembled for GWLF model runs. Land use data consists of the areas of the various rural and urban runoff sources. Required weather data are daily temperature (°C) and precipitation (cm) records for the simulation period. Transport parameters are the necessary hydrologic, erosion and sediment data and nutrient parameters are the various nitrogen and phosphorus data required for loading calculations. This appendix discusses general procedures for estimation of these parameters. Examples of parameter estimation are provided in Appendix C.

Land Use Data

Runoff source areas are identified from land use maps, soil surveys and aerial or satellite photography (Haith & Tubbs, 1981; Delwiche & Haith, 1983). In principle, each combination of soil, surface cover and management must be designated. For example, each corn field in the watershed can be considered a source area, and its area determined and estimates made for runoff curve number and soil erodibility and topographic, cover and supporting practice factors. In practice, these fields can often be aggregated, as in Appendix C into one "corn" source area with area-weighted parameters. Each urban land use is broken down into impervious and pervious areas. The former are solid surfaces such as streets, driveways, parking lots and roofs.

Weather Data

Daily precipitation and temperature data are obtained from meteorologic records and assembled in the data file **WEATHER.DAT**. An example of this file is given in Appendix D. Weather data must be organized in "weather years" which are consistent with model assumptions. Both the groundwater and sediment portions of GWLF require that simulated years begin at a time when soil moisture conditions are known and runoff events have "flushed" the watershed of the previous year's accumulated sediment. In the eastern U.S. this generally corresponds to early spring and hence in such locations an April - March weather year is appropriate.

Transport Parameters

A sample set of hydrologic, erosion and sediment parameters required for the data file **TRANSPRT.DAT** is given in Appendix D.

Runoff Curve Numbers. Runoff curve numbers for rural and urban land uses have been assembled in the U.S. Soil Conservation Service's Technical Release No. 55, 2nd edition (Soil Conservation Service, 1986). These curve numbers are based on the soil hydrologic groups given in Table B-1. Curve numbers for average antecedent moisture conditions ($CN2_k$) are listed in Tables B-2 through B-5. Barnyard curve numbers are given by Overcash & Phillips (1978) as $CN2_k$ = 90, 98 and 100 for earthen areas, concrete pads and roof areas draining into the barnyard, respectively.

Evapotranspiration Cover Coefficients. Estimation of evapotranspiration cover coefficients for watershed studies is problematic. Cover coefficients may be determined from published seasonal values such as those given in Tables B-6 and B-7. However, their use often requires estimates of crop development (planting dates, time to maturity, etc.) which may not be available. Moreover, a single set of consistent values is seldom available for all of a watershed's land uses.

Soil Hydrologic Group	Description
A	Low runoff potential and high infiltration rates even when thoroughly wetted. Chiefly deep, well to excessively drained sands or gravels. High rate of water transmission (> 0.75 cm/hr).
B	Moderate infiltration rates when thoroughly wetted. Chiefly moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. Moderate rate of water transmission (0.40-0.75 cm/hr).
C	Low infiltration rates when thoroughly wetted. Chiefly soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. Low rate of water transmission (0.15-0.40 cm/hr).
D	High runoff potential. Very low infiltration rates when thoroughly wetted. Chiefly clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, or shallow soils over nearly impervious material. Very low rate of water transmission (0-0.15 cm/hr).
Disturbed Soils (Major altering of soil profile by construction, development):	
A	Sand, loamy sand, sandy loam.
B	Silt loam, loam
C	Sandy clay loam
D	Clay loam, silty clay loam, sandy clay, silty clay, clay.

Table B-1. Descriptions of Soil Hydrologic Groups (Soil Conservation Service, 1986)

A simplified procedure can be developed, however, based on a few general observations:

1. Cover coefficients should in principle vary between 0 and 1.
2. Cover coefficients will approach their maximum value when plants have developed full foliage.
3. Because evapotranspiration measures both transpiration and evaporation of soil water, the lower limit for cover coefficients will be greater than zero. This lower limit essentially represents a situation without any plant cover.
4. The protection of soil by impervious surfaces prevents evapotranspiration.

The cover coefficients given for annual crops in Table B-6 fall to approximately 0.3 before planting and after harvest. Similarly, cover coefficients for forests reach minimum values of 0.2 to 0.3 when leaf area indices approach zero. This suggests that monthly cover coefficients for can be given the value 0.3 when foliage is absent and 1.0 otherwise. Perennial crops, such as grass, hay, meadow, and pasture, crops grown in flooded soil, such as rice, and conifers can be given a cover coefficient of 1.0 year round.

Land Use/Cover		Hydrologic Condition	Soil Hydrologic Group			
			A	B	C	D
Fallow	Bare Soil	-	77	86	91	94
Crop residue cover (CR)		Poor[a]	76	85	90	93
		Good	74	83	88	90
Row Crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C&T)	Poor	66	74	80	82
		Good	62	71	78	81
	C&T + CR	Poor	65	73	79	81
		Good	61	70	77	80
Small Grains	SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T	Poor	61	72	79	82
		Good	59	70	78	81
	C&T + CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded or broadcast legumes or rotation meadow	SR	Poor	66	77	85	89
		Good	58	72	81	85
	C	Poor	64	75	83	85
		Good	55	69	78	83
	C&T	Poor	63	73	80	83
		Good	51	67	76	80

[a] Hydrologic condition is based on a combination of factors that affect infiltration and runoff, including (a) density and canopy of vegetative areas, (b) amount of year-round cover, (c) amount of close-seeded legumes in rotations, (d) percent of residue cover on the land surface (good ≥ 20%), and (e) degree of surface roughness.

Table B-2. Runoff Curve Numbers (Antecedent Moisture Condition II) for Cultivated Agricultural Land (Soil Conservation Service, 1986).

Land Use/Cover	Hydrologic Condition	Soil Hydrologic Group A	B	C	D
Pasture, grassland or range - continuous forage for grazing	Poor[a]	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow - continuous grass, protected from grazing, generally mowed for hay	-	30	58	71	78
Brush - brush/weeds/grass mixture with brush the major element	Poor[b]	48	67	77	83
	Fair	35	56	70	77
	Good	30	48	65	73
Woods/grass combination (orchard or tree farm)[c]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods	Poor[d]	45	66	77	83
	Fair	36	60	73	79
	Good	30	55	70	77
Farmsteads - buildings, lanes, driveways and surrounding lots	-	59	74	82	86

[a] Poor: < 50% ground cover or heavily grazed with no mulch; Fair: 50 to 75% ground cover and not heavily grazed; Good: > 75% ground cover and lightly or only occasionally grazed.

[b] Poor: < 50% ground cover; Fair: 50 to 75% ground cover; Good: > 75% ground cover.

[c] Estimated as 50% woods, 50% pasture.

[d] Poor: forest litter, small trees and brush are destroyed by heavy grazing or regular burning; Fair: woods are grazed but not burned and some forest litter covers the soil; Good: Woods are protected from grazing and litter and brush adequately cover the soil.

Table B-3. Runoff Curve Numbers (Antecedent Moisture Condition II) for other Rural Land (Soil Conservation Service, 1986).

Land Use/Cover	Hydrologic Condition	Soil Hydrologic Group A	B	C	D
Herbaceous - grass, weeds & low-growing brush; brush the minor component	Poor[a]	-	80	87	93
	Fair	-	71	81	89
	Good	-	62	74	85
Oak/aspen - oak brush, aspen, mountain mahogany, bitter brush, maple and other brush	Poor	-	66	74	79
	Fair	-	48	57	63
	Good	-	30	41	48
Pinyon/juniper - pinyon, juniper or both; grass understory	Poor	-	75	85	89
	Fair	-	58	73	80
	Good	-	41	61	71
Sagebrush with grass understory	Poor	-	67	80	85
	Fair	-	51	63	70
	Good	-	35	47	55
Desert scrub - saltbush, greasewood, creosotebrush, blackbrush, bursage, palo verde, mesquite and cactus	Poor	63	77	85	88
	Fair	55	72	81	86
	Good	49	68	79	84

[a] Poor: < 30% ground cover (litter, grass and brush overstory); Fair: 30 to 70% ground cover; Good: > 70% ground cover.

Table B-4. Runoff Curve Numbers (Antecedent Moisture Condition II) for Arid and Semiarid Rangelands (Soil Conservation Service, 1986).

Land Use	Soil Hydrologic Group A	B	C	D
Open space (lawns, parks, golf courses, cemeteries, etc.):				
Poor condition (grass cover < 50%)	68	79	86	89
Fair condition (grass cover 50-75%)	49	69	79	84
Good condition (grass cover > 75%)	39	61	74	80
Impervious areas:				
Paved parking lots, roofs, driveways, etc.)	98	98	98	98
Streets and roads:				
Paved with curbs & storm sewers	98	98	98	98
Paved with open ditches	83	89	92	93
Gravel	76	85	89	91
Dirt	72	82	87	89
Western desert urban areas:				
Natural desert landscaping (pervious areas, only)	63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1-2 in sand or gravel mulch and basin borders)	96	96	96	96

Table B-5. Runoff Curve Numbers (Antecedent Moisture Condition II) for Urban Areas (Soil Conservation Service, 1986).

	% of Growing Season										
Crop	0	10	20	30	40	50	60	70	80	90	100
Field corn	0.45	0.51	0.58	0.66	0.75	0.85	0.96	1.08	1.20	1.08	0.70
Grain sorgh	0.30	0.40	0.65	0.90	1.10	1.20	1.10	0.95	0.80	0.65	0.50
Wint wheat	1.08	1.19	1.29	1.35	1.40	1.38	1.36	1.23	1.10	0.75	0.40
Cotton	0.40	0.45	0.56	0.76	1.00	1.14	1.19	1.11	0.83	0.58	0.40
Sugar beets	0.30	0.35	0.41	0.56	0.73	0.90	1.08	1.26	1.44	1.30	1.10
Cantaloupe	0.30	0.30	0.32	0.35	0.46	0.70	1.05	1.22	1.13	0.82	0.44
Potatoes	0.30	0.40	0.62	0.87	1.06	1.24	1.40	1.50	1.50	1.40	1.26
Papago peas	0.30	0.40	0.66	0.89	1.04	1.16	1.26	1.25	0.63	0.28	0.16
Beans	0.30	0.35	0.58	1.05	1.07	0.94	0.80	0.66	0.53	0.43	0.36
Rice	1.00	1.06	1.13	1.24	1.38	1.55	1.58	1.57	1.47	1.27	1.00

Table B-6. Evapotranspiration Cover Coefficients for Annual Crops - Measured as Ratio of Evapotranspiration to Lake Evaporation (Davis & Sorensen, 1969; cited in Novotny & Chesters, 1981).

	Alfalfa	Pasture	Grapes	Citrus Orchards	Deciduous Orchards	Sugarcane
Jan	0.83	1.16	-	0.58	-	0.65
Feb	0.90	1.23	-	0.53	-	0.50
Mar	0.96	1.19	0.15	0.65	-	0.80
Apr	1.02	1.09	0.50	0.74	0.60	1.17
May	1.08	0.95	0.80	0.73	0.80	1.21
June	1.14	0.83	0.70	0.70	0.90	1.22
July	1.20	0.79	0.45	0.81	0.90	1.23
Aug	1.25	0.80	-	0.96	0.80	1.24
Sept	1.22	0.91	-	1.08	0.50	1.26
Oct	1.18	0.91	-	1.03	0.20	1.27
Nov	1.12	0.83	-	0.82	0.20	1.28
Dec	0.86	0.69	-	0.65	-	0.80

Table B-7. Evapotranspiration Cover Coefficients for Perennial Crops - Measured as Ratio of Evapotranspiration to Lake Evaporation (Davis & Sorensen, 1969; cited in Novotny & Chesters, 1981).

In urban areas, ground cover is a mixture of trees and grass. It follows that cover factors for pervious areas are weighted averages of the perennial crop, hardwood, and softwood cover factors. It may be difficult to determine the relative fractions of urban areas with these covers. Since these covers would have different values only during dormant seasons, it is reasonable to assume a constant month value of 1.0 for urban pervious surfaces and zero for impervious surfaces.

These approximate cover coefficients are given in Table B-8. Table B-9 list mean monthly values of daylight hours (H_t) for use in Equation A-31.

Cover	Dormant Season	Growing Season
Annual crops (foliage only in growing season)	0.3	1.0
Perennial crops (year-round foliage: grass, pasture, meadow, etc.)	1.0	1.0
Saturated crops (rice)	1.0	1.0
Hardwood (deciduous) forests & orchards	0.3	1.0
Softwood (conifer) forests & orchards	1.0	1.0
Disturbed areas & bare soil (barn yards, fallow, logging trails, construction and mining)	0.3	0.3
Urban areas (I = impervious fraction)	1 - I	1 - I

Table B-8. Approximate Values for Evapotranspiration Cover Coefficients.

	Latitude North (°)												
	48	46	44	42	40	38	36	34	32	30	28	26	24
	(hr/day)												
Jan	8.7	8.9	9.2	9.3	9.5	9.7	9.9	10.0	10.2	10.3	10.5	10.6	10.7
Feb	10.0	10.2	10.3	10.4	10.5	10.6	10.7	10.8	10.9	11.0	11.1	11.1	11.2
Mar	11.7	11.7	11.7	11.7	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.9
Apr	13.4	13.3	13.2	13.1	13.0	13.0	12.9	12.8	12.8	12.7	12.7	12.6	12.6
May	14.9	14.7	14.5	14.3	14.1	14.0	13.8	13.7	13.6	13.5	13.4	13.2	13.1
Jun	15.7	15.4	15.2	15.0	14.7	14.5	14.3	14.2	14.0	13.9	13.7	13.6	13.4
Jul	15.3	15.0	14.8	14.6	14.4	14.3	14.1	14.0	13.8	13.7	13.5	13.4	13.3
Aug	14.0	13.8	13.7	13.6	13.6	13.4	13.3	13.2	13.3	13.0	13.0	12.9	12.8
Sep	12.3	12.3	12.3	12.3	12.2	12.2	12.2	12.2	12.2	12.2	12.1	12.1	12.1
Oct	10.6	10.7	10.8	10.9	11.0	11.0	11.1	11.2	11.2	11.3	11.3	11.4	11.4
Nov	9.1	9.3	9.5	9.7	9.8	10.0	10.1	10.2	10.4	10.5	10.6	10.7	10.9
Dec	8.3	8.5	8.8	9.0	9.2	9.4	9.6	9.8	10.0	10.1	10.3	10.4	10.6

Table B-9. Mean Daylight Hours (Mills et al., 1985).

Groundwater. The groundwater portion of GWLF requires estimates of available unsaturated zone available soil moisture capacity U^*, recession constant r and seepage constant s.

In principle, U^* is equivalent to a mean watershed maximum rooting depth multiplied by a mean volumetric soil available water capacity. The latter also requires determination of a mean unsaturated zone depth, and this is probably impractical for most watershed studies. A default value of 10 cm can be assumed for pervious areas, corresponding to a 100 cm rooting depth and a 0.1 cm/cm volumetric available water capacity. These values appear typical for a wide range of plants (Jensen et al., 1989; U.S. Forest Service, 1980) and soils (Rawls et al., 1982).

Estimates of the recession constant r can be estimated from streamflow records by standard hydrograph separation techniques (Chow, 1964). During a period of hydrograph recession, the rate of change in shallow saturated zone water S(t) (cm) is given by the linear reservoir relationship

$$\frac{dS}{dt} = -r\,S \tag{B-1}$$

or,

$$S(t) = S(0)\,e^{-rt} \tag{B-2}$$

where S(0) is the shallow saturated zone moisture at t = 0. Groundwater discharge to the stream G(t) (cm) at time t is

$$G(t) = r\,S(t) = r\,S(0)\,e^{-rt} \tag{B-3}$$

During periods of streamflow recession, it is assumed that runoff is negligible, and hence streamflow F(t) (cm) consists of groundwater discharge given by Equation B-3; i.e., F(t) = G(t). A recession constant can be estimated from two streamflows $F(t_1)$, $F(t_2)$ measured on days t_1 and t_2 ($t_2 > t_1$) during the hydrograph recession. The ratio $F(t_1)/F(t_2)$ is

$$\frac{F(t_1)}{F(t_2)} = \frac{r\,S(0)\,e^{-rt_1}}{r\,S(0)\,e^{-rt_2}} = e^{r(t_2 - t_1)} \tag{B-4}$$

The recession constant is thus given by

$$r = \frac{\ln\,[F(t_1)/F(t_2)]}{t_2 - t_1} \tag{B-5}$$

Recession constants are measured for a number of hydrographs and an average value is used for the simulations. Typical values range from 0.01 to 0.2

No standard techniques are available for estimating the rate constant for deep seepage loss (s). The most conservative approach is to assume that s = 0 (all precipitation exits the watershed in evapotranspiration or streamflow). Otherwise the constant must be determined by calibration.

Erosion and Sediment. The factors K_k, $(LS)_k$, C_k and P_k for the Universal Soil Loss Equation must be specified as the product $K_k\,(LS)_k\,C_k\,P_k$ for each rural runoff source area. Values K_k, C_k and P_k are given for a range of soils and conditions in Tables B-10 - B-13. More complete sets of values are provided in Mills et al. (1985) and Wischmeier & Smith (1978). The $(LS)_k$ factor is calculated for each source area k as in Wischmeier & Smith (1978):

$$LS = (0.045x_k)^b\,(65.41\sin^2\Theta_k + 4.56\sin\Theta_k + 0.065) \qquad \text{(B-6)}$$

$$\Theta_k = \tan^{-1}(ps_k/100) \qquad \text{(B-7)}$$

in which x_k = slope length (m) and ps_k = per cent slope.

The rainfall erosivity coefficient a, for Equation A-12 can be estimated using methods developed by Selker et al. (1990). General values for the rainfall erosivity zones shown in Figure B-1 are given in Table B-14.

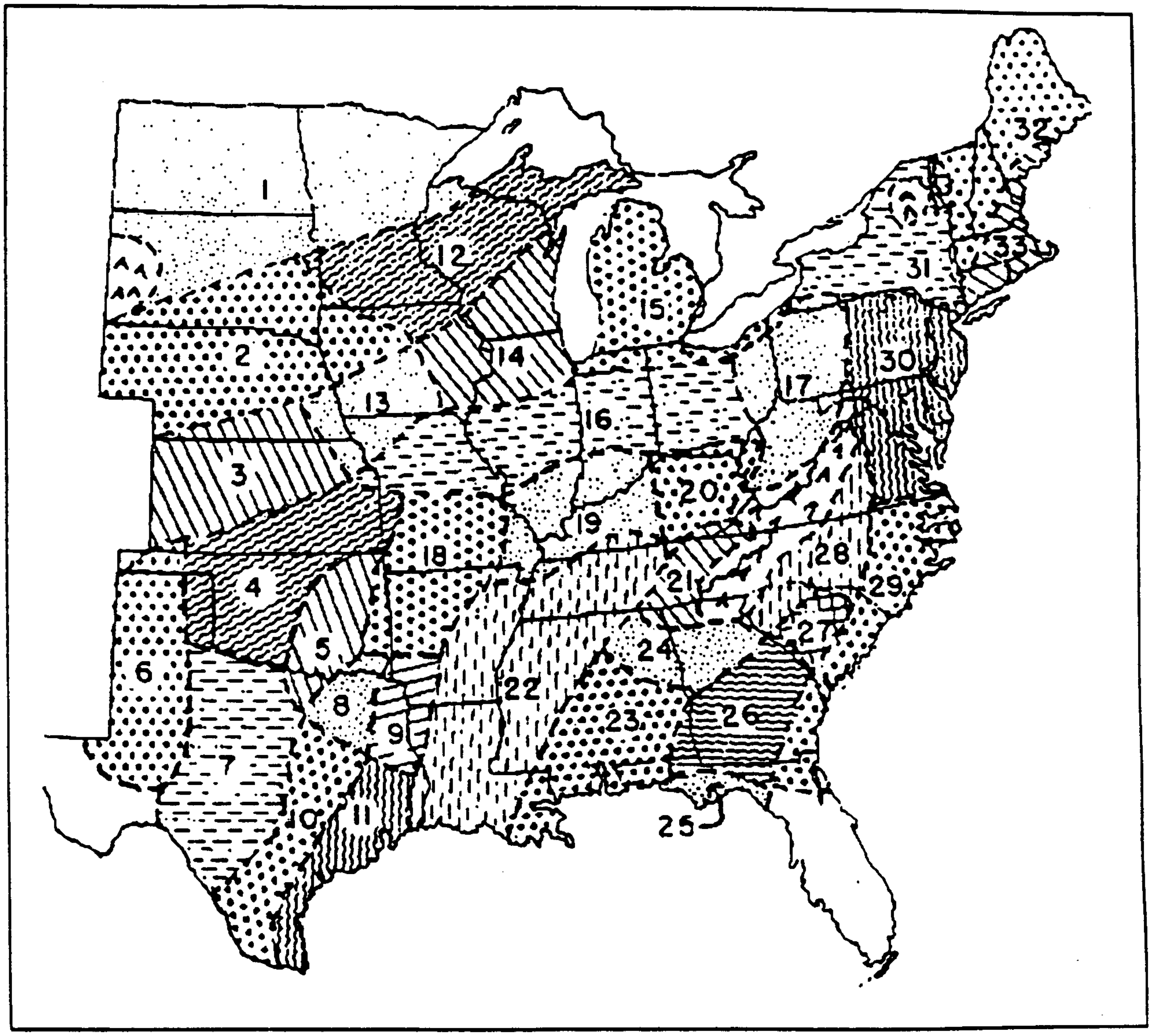


Figure B-1. Rainfall Erosivity Zones in Eastern U.S. (Wischmeier & Smith, 1978).

Watershed sediment delivery ratios are most commonly obtained from the area-based relationship shown in Figure B-2.

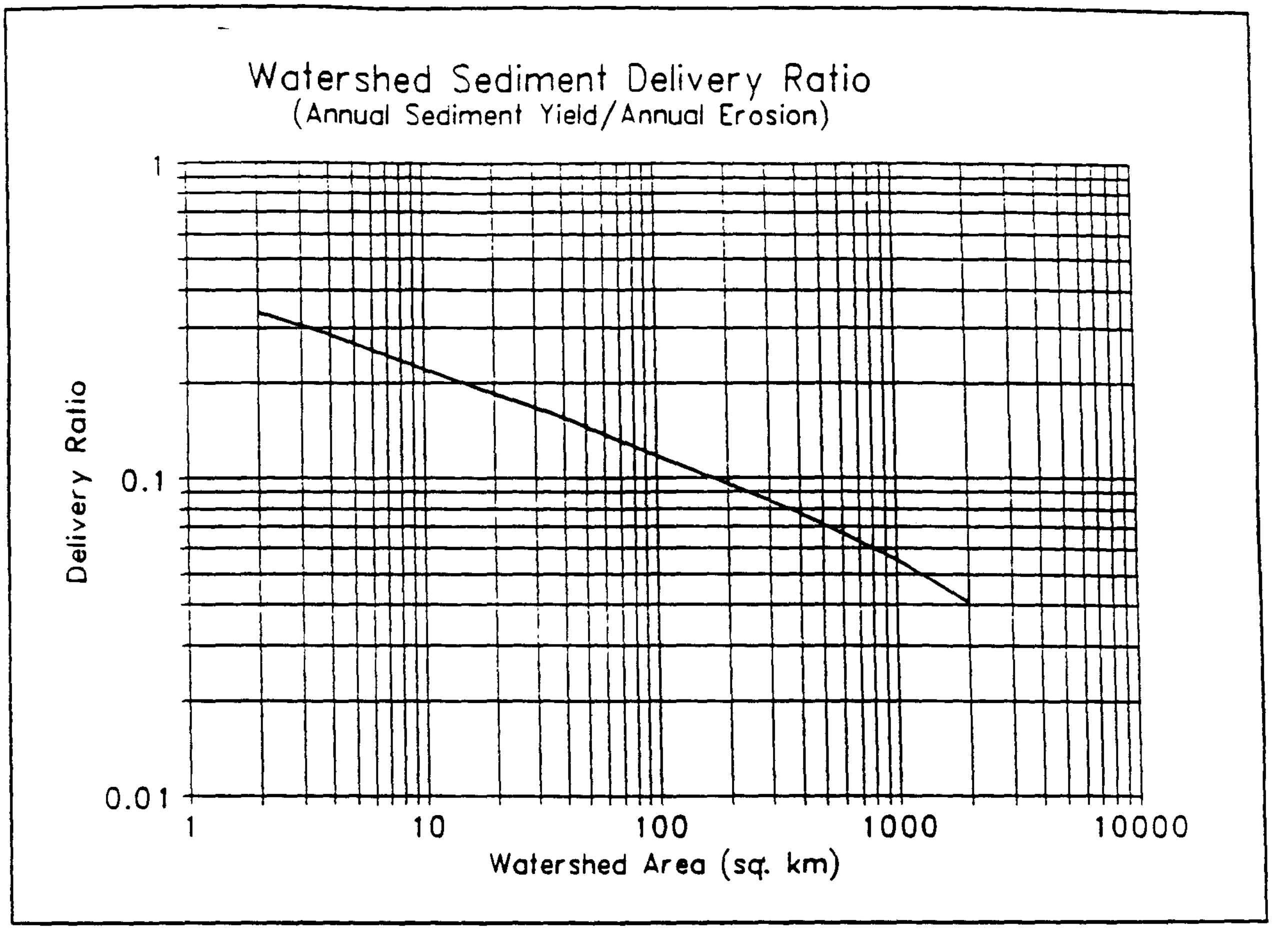


Figure B-2. Watershed Sediment Delivery Ratio (Vanoni, 1975).

	Organic Matter Content (%)		
Texture	<0.5	2	4
Sand	0.05	0.03	0.02
Fine sand	0.16	0.14	0.10
Very fine sand	0.42	0.36	0.28
Loamy sand	0.12	0.10	0.08
Loamy fine sand	0.24	0.20	0.16
Loamy very fine sand	0.44	0.38	0.30
Sandy loam	0.27	0.24	0.19
Fine sandy loam	0.35	0.30	0.24
Very fine sandy loam	0.47	0.41	0.33
Loam	0.38	0.34	0.29
Silt loam	0.48	0.42	0.33
Silt	0.60	0.52	0.42
Sandy clay loam	0.27	0.25	0.21
Clay loam	0.28	0.25	0.21
Silty clay loam	0.37	0.32	0.26
Sandy clay	0.14	0.13	0.12
Silty clay	0.25	0.23	0.19
Clay	-	0.13-0.29	-

Table B-10. Values of Soil Erodibility Factor (K) (Stewart et al., 1975).

Crop, rotation & management[b/]	Productivity[a/] High	 Moderate
Continuous fallow, tilled up and down slope	1.00	1.00
CORN		
1 C, RdR, fall TP, conv (1)	0.54	0.62
2 C, RdR, spring TP, conv (1)	0.50	0.59
3 C, RdL, fall TP, conv (1)	0.42	0.52
4 C, RdR, wc seeding, spring TP, conv (1)	0.40	0.49
5 C, RdL, standing, spring TP, conv (1)	0.38	0.48
6 C, fall shred stalks, spring TP, conv (1)	0.35	0.44
7 C(silage)-W(RdL,fall TP) (2)	0.31	0.35
8 C, RdL, fall chisel, spring disk, 40-30% re (1)	0.24	0.30
9 C(silage), W wc seeding, no-till pl in c-k W (1)	0.20	0.24
10 C(RdL)-W(RdL,spring TP) (2)	0.20	0.28
11 C, fall shred stalks, chisel pl, 40-30% re (1)	0.19	0.26
12 C-C-C-W-M, RdL, TP for C, disk for W (5)	0.17	0.23
13 C, RdL, strip till row zones, 55-40% re (1)	0.16	0.24
14 C-C-C-W-M-M, RdL, TP for C, disk for W (6)	0.14	0.20
15 C-C-W-M, RdL, TP for C, disk for W (4)	0.12	0.17
16 C, fall shred, no-till pl, 70-50% re (1)	0.11	0.18
17 C-C-W-M-M, RdL, TP for C, disk for W (5)	0.087	0.14
18 C-C-C-W-M, RdL, no-till pl 2nd & 3rd C (5)	0.076	0.13
19 C-C-W-M, RdL, no-till pl 2d C (4)	0.068	0.11
20 C, no-till pl in c-k wheat, 90-70% re (1)	0.062	0.14
21 C-C-C-W-M-M, no-till pl 2d & 3rd C (6)	0.061	0.11
22 C-W-M, RdL, TP for C, disk for W (3)	0.055	0.095
23 C-C-W-M-M, RdL, no-till pl 2d C (5)	0.051	0.094
24 C-W-M-M, RdL, TP for C, disk for W (4)	0.039	0.074
25 C-W-M-M-M, RdL, TP for C, disk for W (5)	0.032	0.061
26 C, no-till pl in c-k sod, 95-80% re (1)	0.017	0.053
COTTON[/c]		
27 Cot, conv (western plains) (1)	0.42	0.49
28 Cot, conv (south) (1)	0.34	0.40
MEADOW (HAY)		
29 Grass & legume mix	0.004	0.01
30 Alfalfa, lespedeza or sericia	0.020	-
31 Sweet clover	0.025	-
SORGHUM, GRAIN (western plains)		
32 RdL, spring TP, conv (1)	0.43	0.53
33 No-till pl in shredded 70-50% re	0.11	0.18
SOYBEANS[/c]		
34 B, RdL, spring TP, conv (1)	0.48	0.54
35 C-B, TP annually, conv (2)	0.43	0.51
36 B, no-till pl	0.22	0.28
37 C-B, no-till pl, fall shred C stalks (2)	0.18	0.22

Table B-11. CONTINUED

Crop, rotation & management[b]	Productivity[a]	
	High	Moderate
WHEAT		
38 W-F, fall TP after W (2)	0.38	-
39 W-F, stubble mulch, 500 lb re (2)	0.32	-
40 W-F, stubble mulch, 1000 Lb re (2)	0.21	-
41 Spring W, RdL, Sept TP, conv (ND,SD) (1)	0.23	-
42 Winter W, RdL, Aug TP, conv (KS) (1)	0.19	-
43 Spring W, stubble mulch, 750 lb re (1)	0.15	-
44 Spring W, stubble mulch, 1250 lb re (1)	0.12	-
45 Winter W, stubble mulch, 750 lb re (1)	0.11	-
46 Winter W, stubble mulch, 1250 lb re (1)	0.10	-
47 W-M, conv (2)	0.054	-
48 W-M-M, conv (3)	0.026	-
49 W-M-M-M, conv (4)	0.021	-

[a] High level exemplified by long-term yield averages greater than 75 bu/ac corn or 3 ton/ac hay or cotton management that regularly provides good stands and growth.

[b] Numbers in parentheses indicate numbers of years in the rotation cycle. (1) indicates a continuous one-crop system.

[c] Grain sorghum, soybeans or cotton may be substituted for corn in lines 12, 14, 15, 17-19, 21-25 to estimate values for sod-based rotations.

Abbreviations:

B	soybeans	F	fallow
C	corn	M	grass & legume hay
c-k	chemically killed	pl	plant
conv	conventional	W	wheat
cot	cotton	wc	winter cover

lb re	pounds of residue per acre remaining on surface after new crop seeding
% re	percentage of soil surface covered by residue mulch after new crop seeding
xx-yy% re	xx% cover for high productivity, yy% for moderate
RdR	residues (corn stover, straw, etc.) removed or burned
RdL	residues left on field (on surface or incorporated)
TP	turn plowed (upper 5 or more inches of soil inverted, covering residues

Table B-11. Generalized Values of Cover and Management Factor (C) for Field Crops East of the Rocky Mountains (Stewart _et al._, 1975).

Cover	Value
Permanent pasture, idle land, unmanaged woodland	
95-100% ground cover	
as grass	0.003
as weeds	0.01
80% ground cover	
as grass	0.01
as weeds	0.04
60% ground cover	
as grass	0.04
as weeds	0.09
Managed woodland	
75-100% tree canopy	0.001
40-75% tree canopy	0.002-0.004
20-40% tree canopy	0.003-0.01

Table B-12. Values of Cover and Management Factor (C) for Pasture and Woodland (Novotny & Chesters, 1981).

Practice Slope(%):	1.1-2	2.1-7	7.1-12	12.1-18	18.1-24
No support practice	1.00	1.00	1.00	1.00	1.00
Contouring	0.60	0.50	0.60	0.80	0.90
Contour strip cropping					
R-R-M-M[a]	0.30	0.25	0.30	0.40	0.45
R-W-M-M	0.30	0.25	0.30	0.40	0.45
R-R-W-M	0.45	0.38	0.45	0.60	0.68
R-W	0.52	0.44	0.52	0.70	0.90
R-O	0.60	0.50	0.60	0.80	0.90
Contour listing or ridge planting	0.30	0.25	0.30	0.40	0.45
Contour terracing[b]	$0.6/\sqrt{n}$	$0.5/\sqrt{n}$	$0.6/\sqrt{n}$	$0.8/\sqrt{n}$	$0.9/\sqrt{n}$

[a] R = row crop, W = fall-seeded grain, M = meadow. The crops are grown in rotation and so arranged on the field that row crop strips are always separated by a meadow or winter-grain strip.

[b] These factors estimate the amount of soil eroded to the terrace channels. To obtain off-field values, multiply by 0.2. n = number of approximately equal length intervals into which the field slope is divided by the terraces. Tillage operations must be parallel to the terraces.

Table B-13. Values of Supporting Practice Factor (P) (Stewart et al., 1975).

Zone[a]	Location	Season[b] Cool	 Warm
1	Fargo ND	0.08	0.30
2	Sioux City IA	0.13	0.35
3	Goodland KS	0.07	0.15
4	Wichita KS	0.20	0.30
5	Tulsa OK	0.21	0.27
6	Amarillo TX	0.30	0.34
7	Abilene TX	0.26	0.34
8	Dallas TX	0.28	0.37
9	Shreveport LA	0.22	0.32
10	Austin TX	0.27	0.41
11	Houston TX	0.29	0.42
12	St. Paul MN	0.10	0.26
13	Lincoln NE	0.26	0.24
14	Dubuque IA	0.14	0.26
15	Grand Rapids MI	0.08	0.23
16	Indianapolis IN	0.12	0.30
17	Parkersburg WV	0.08	0.26
18	Springfield MO	0.17	0.23
19	Evansville IN	0.14	0.27
20	Lexington KY	0.11	0.28
21	Knoxville TN	0.10	0.28
22	Memphis TN	0.11	0.20
23	Mobile AL	0.15	0.19
24	Atlanta GA	0.15	0.34
25	Apalachacola FL	0.22	0.31
26	Macon GA	0.15	0.40
27	Columbia SC	0.08	0.25
28	Charlotte NC	0.12	0.33
29	Wilmington NC	0.16	0.28
30	Baltimore MD	0.12	0.30
31	Albany NY	0.06	0.25
32	Caribou ME	0.07	0.13
33	Hartford CN	0.11	0.22

[a] Zones given in Figure B-1.

[b] Cool season: Oct - Mar; Warm season: Apr - Sept.

Table B-14. Rainfall Erosivity Coefficients (a) for Erosivity Zones in Eastern U.S. (Selker et al., 1990).

Initial Conditions. Several initial conditions must be provided in the **TRANSPRT.DAT** file: initial unsaturated and shallow saturated zone soil moistures (U_1 and S_1), snowmelt water (SN_1) and antecedent rain + snowmelt for the five previous days. It is likely that these values will be uncertain in many applications. However, they will not affect model results for more than the first month or two of the simulation period. It is generally most practical to assign arbitrary initial values (U^* for U_1 and zero for the remaining variables) and to discard the first year of the simulation results.

Nutrient Parameters

A sample set of nutrient parameters required for the data file **NUTRIENT.DAT** is given in Appendix D.

Although the GWLF model will be most accurate when nutrient data are calibrated to local conditions, a set of default parameters has been developed to facilitate uncalibrated applications. Obviously these parameters, which are average values obtained from published water pollution monitoring studies, are only approximations of conditions in any watershed.

Rural and Groundwater Sources. Solid-phase nutrients in sediment from rural sources can be estimated as the average soil nutrient content multiplied by an enrichment ratio. Soil nutrient levels can be determinec from soil samples, soil surveys or general maps such as those given in Figures B-3 and B-4. A value of 2.C for the enrichment ratio falls within the mid-range of reported ratios and can be used in absence of more specific data (McElroy et al., 1976; Mills et al., 1985).

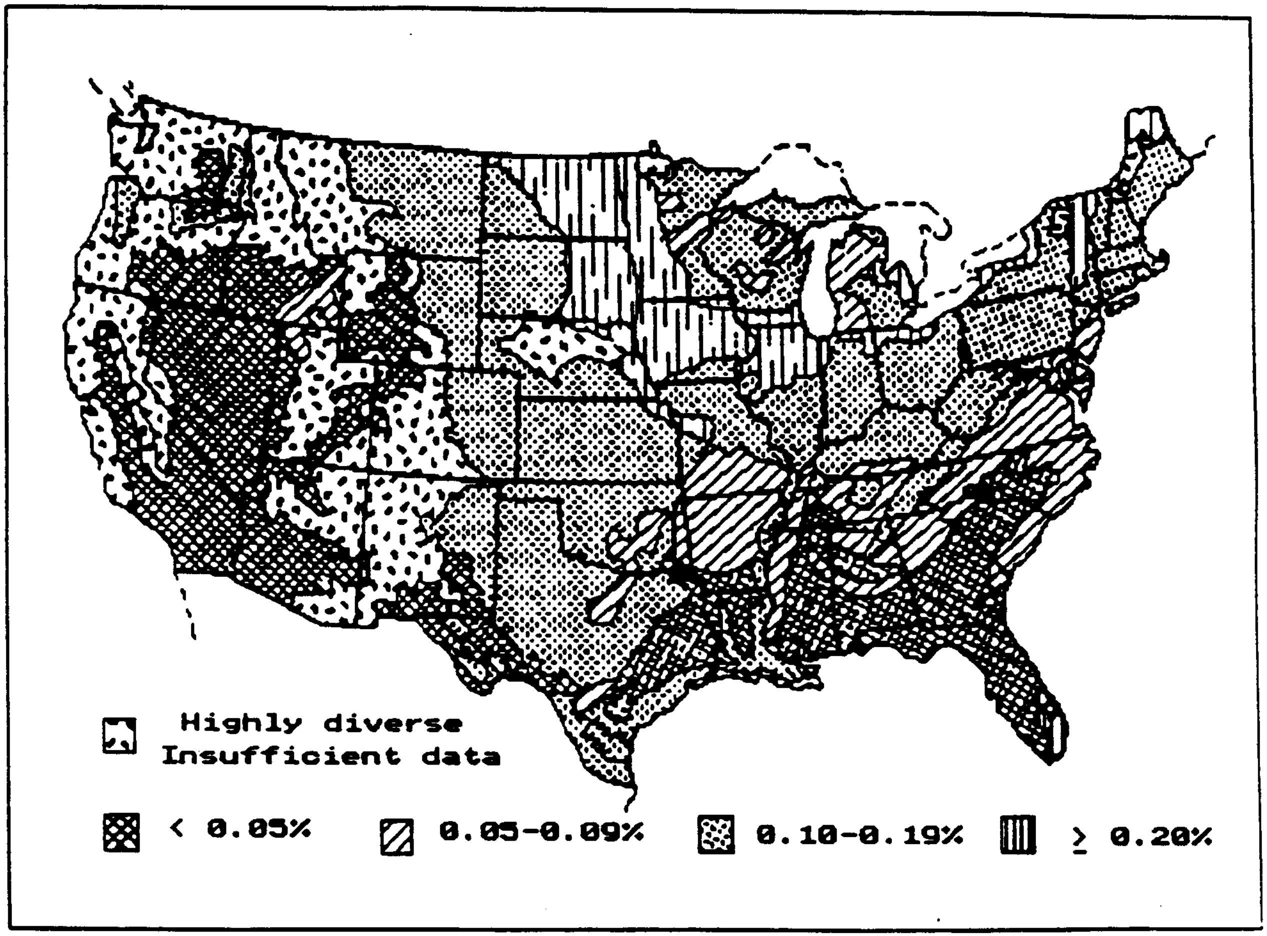


Figure B-3. Nitrogen in Surface 30 cm of Soils (Parker et al., 1946; Mills et al., 1985).

Default flow-weighted mean concentrations of dissolved nitrogen and phosphorus in agricultural runof are given in Table B-15. The cropland and barnyard data are from multi-year storm runoff sampling studie in South Dakota (Dornbush et al., 1974) and Ohio (Edwards et al., 1972). The concentrations for snowmel runoff from fields with manure on the soil surface are taken from a manual prepared by U. S. Departmen of Agriculture scientists (Gilbertson et al., 1979).

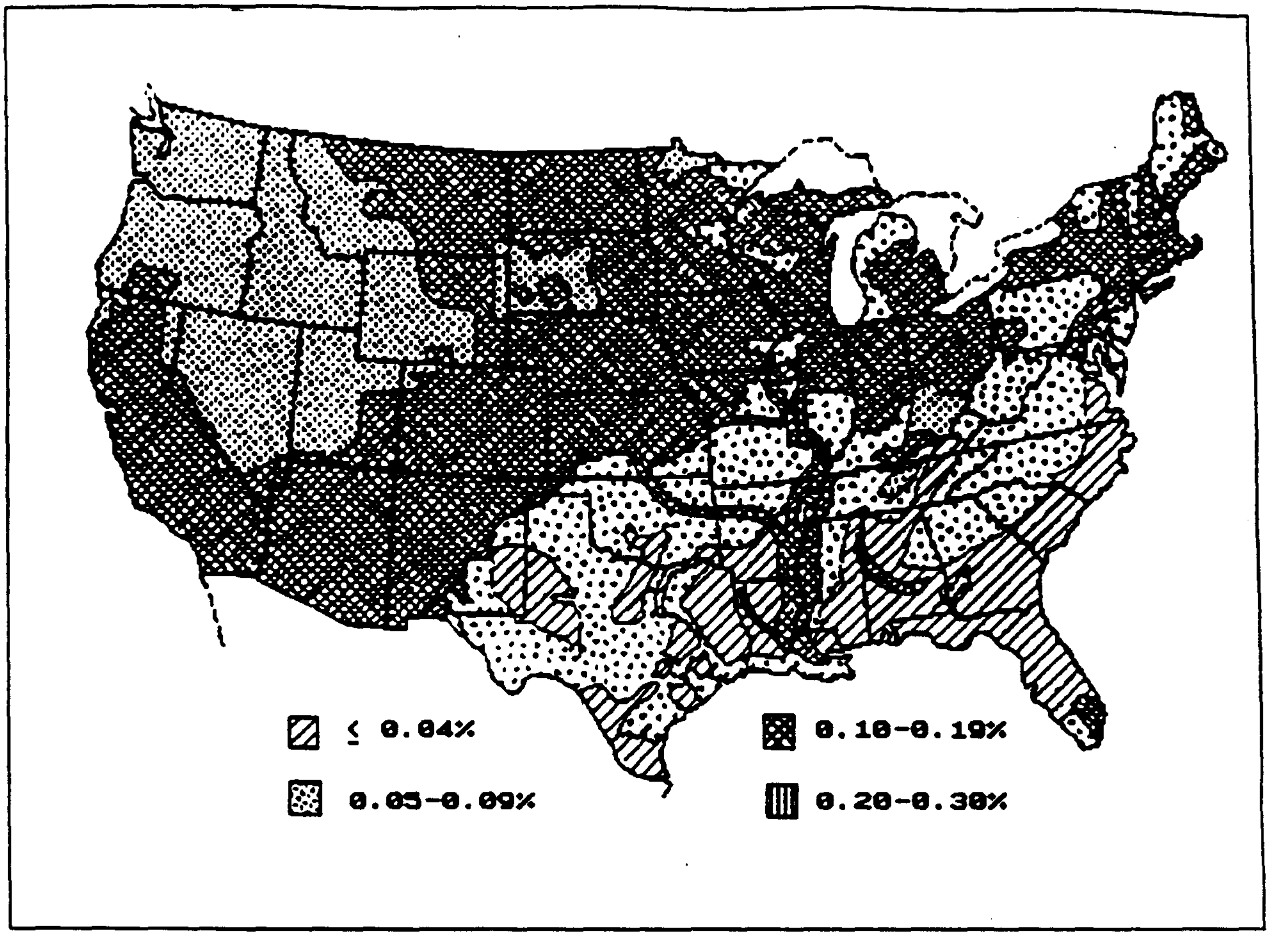


Figure B-4. P_2O_5 in Surface 30 cm of Soils (P_2O_5 is 44% phosphorus) (Parker et al., 1946; Mills et al., 1985).

Default values for nutrient concentrations in groundwater discharge can be inferred from the U.S. Eutrophication Survey results (Omernik, 1977) given in Table B-16. These data are mean concentrations computed from 12 monthly streamflow samples in watersheds free of point sources. Since such limited sampling is unlikely to capture nutrient fluxes from storm runoff, the streamflow concentrations can be assumed to represent groundwater discharges to streams.

Dissolved nutrient data for forest runoff are essentially nonexistent. Runoff is a small component of streamflow from forest areas and studies of forest nutrient flux are based on streamflow rather than runoff sampling. Hence the only possible default option is the use of the streamflow concentrations from the "≥ 90% Forest" category in Table B-16 as estimates of runoff concentrations.

Default values for urban nutrient accumulation rates are provided in Table B-17. These values were developed for Northern Virginia conditions and are probably suitable for smaller and relatively new urban areas. They would likely underestimate accumulations in older large cities.

Septic Systems. Representative values for septic system nutrient parameters are given in Table B-18. Per capita nutrient loads in septic tank effluent were estimated from typical flows and concentrations. The EPA Design Manual (U.S. Environmental Protection Agency, 1980) indicates 170 *l*/day as a representative wastewater flow from on-site wastewater disposal systems. Alhajjar et al. (1989) measured mean nitrogen and phosphorus concentrations in septic tank effluents of 73 and 14 mg/*l*, respectively. The latter concentration is based on use of phosphate detergents. When non-phosphate detergents are used, the concentration dropped to 7.9 mg/*l*. These concentrations were combined with the 170 *l*/day flow to produce the effluent nutrient loads given in Table B-18.

Nutrient uptake by plants (generally grasses) growing over the septic system adsorption field are frankly speculative. Brown & Thomas (1978) suggest that if the grass clippings are harvested, nutrients from a septic system effluent can support at least twice the normal yield of grass over the absorption field. Petrovic & Cornman (1982) suggest that retention of turf grass clippings can reduce required fertilizer applications by 25%, thus implying nutrient losses of 75% of uptakes. It appears that a conservative estimate of nutrient losses from plant cover would be 75% of the nutrient uptake of from a normal annual yield of grass. Reed _et al_. (1988) reported that Kentucky bluegrass annually utilizes 200-270 kg/ha nitrogen and 45 kg/ha phosphorus. Using the 200 kg/ha nitrogen value, and assuming a six month growing season and a 20 m^2 per capita absorption area, an estimated 1.6 g/day nitrogen and 0.4 g/day phosphorus are lost by plant uptake on a per capita basis during the growing season. The 20 m^2 adsorption area was based on per bedroom adsorption area recommendations by the U.S. Public Health Service for a soil with average percolation rate (≈ 12 min/cm) (U.S. Public Health Service, 1967).

The remaining information needed are the numbers of people served by the four different types of septic systems (normal, short-circuited, ponded and direct discharge). A starting point for this data will generally be estimates of the unsewered population in the watershed. Local public health officials may be able to estimate the fractions of systems within the area which are of each type. However, the most direct way of generating the information is through a septic systems survey.

Land Use	Nitrogen	Phosphorus
	(------------(mg/*l*)------------)	
Fallow[a]	2.6	0.10
Corn[a]	2.9	0.26
Small grains[a]	1.8	0.30
Hay[a]	2.8	0.15
Pasture[a]	3.0	0.25
Barn yards[b]	29.3	5.10
<u>Snowmelt runoff from manured land</u>[c]:		
Corn	12.2	1.90
Small grains	25.0	5.00
Hay	36.0	8.70

[a] Dornbush *et al*. (1974)

[b] Edwards *et al*. (1972)

[c] Gilbertson *et al*. (1979); manure left on soil surface.

Table B-15. Dissolved Nutrients in Agricultural Runoff.

Watershed Type	Concentrations (mg/*l*) Eastern U.S.	Central U.S.	Western U.S.
<u>Nitrogen</u>[a]:			
≥ 90% Forest	0.19	0.06	0.07
≥ 75% Forest	0.23	0.10	0.07
≥ 50% Forest	0.34	0.25	0.18
≥ 50% Agriculture	1.08	0.65	0.83
≥ 75% Agriculture	1.82	0.80	1.70
≥ 90% Agriculture	5.04	0.77	0.71
<u>Phosphorus</u>[b]:			
≥ 90% Forest	0.006	0.009	0.012
≥ 75% Forest	0.007	0.012	0.015
≥ 50% Forest	0.013	0.015	0.015
≥ 50% Agriculture	0.029	0.055	0.083
≥ 75% Agriculture	0.052	0.067	0.069
≥ 90% Agriculture	0.067	0.085	0.104

[a] Measured as total inorganic nitrogen.

[b] Measured as total orthophosphorus

Table B-16. Mean Dissolved Nutrients Measured in Streamflow by the National Eutrophication Survey (Omernik, 1977).

Land Use	Suspended Solids	BOD	Total Nitrogen	Total Phosphorus
	(----------	kg/ha-day	----------	----------)
Impervious Surfaces				
Single family residential 1.2				
Low density (units/ha < ~~0.5~~)	2.5	0.15	0.045	0.0045
Medium density (units/ha ≥ ~~0.5~~)	6.2	0.22	0.090	0.0112
Townhouses & apartments 1.2	6.2	0.22	0.090	0.0112
High rise residential	3.9	0.71	0.056	0.0067
Institutional	2.8	0.39	0.056	0.0067
Industrial	2.8	0.71	0.101	0.0112
Suburban shopping center	2.8	0.71	0.056	0.0067
Central business district	2.8	0.85	0.101	0.0112
Pervious Surfaces				
Single family residential 1.2				
Low density (units/ha < ~~0.5~~)	1.3	0.08	0.012	0.0016
Medium density (units/ha ≥ ~~0.5~~)	1.1	0.15	0.022	0.0039
Townhouses & apartments 1.2	2.2	0.29	0.045	0.0078
High rise residential	0.8	0.08	0.012	0.0019
Institutional	0.8	0.08	0.012	0.0019
Industrial	0.8	0.08	0.012	0.0019
Suburban shopping center	0.8	0.08	0.012	0.0019
Central business district	0.8	0.08	0.012	0.0019

Table B-17. Contaminant Accumulation Rates for Northern Virginia Urban Areas (Kuo, et al., 1988).

Parameter		Value
e, per capita daily nutrient load in septic tank effluent (g/day)		
Nitrogen		12.0
Phosphorus		
Phosphate detergents use		2.5
Non-phosphate detergents use		1.5
u_m, per capita daily nutrient uptake by plants during month m (g/day)		
Nitrogen:	Growing season	1.6
	Non-growing season	0.0
Phosphorus:	Growing season	0.4
	Non-growing season	0.0

Table B-18. Default Parameter Values for Septic Systems.

APPENDIX C: VALIDATION STUDY

The GWLF model was tested by comparing model predictions with measured streamflow, sediment and nutrient loads from the West Branch Delaware River Basin during a three-year period (April, 1979 - March, 1982). The model was run using the four-year period April, 1978 - March, 1982 and first year results were ignored to eliminate effects of arbitrary initial conditions.

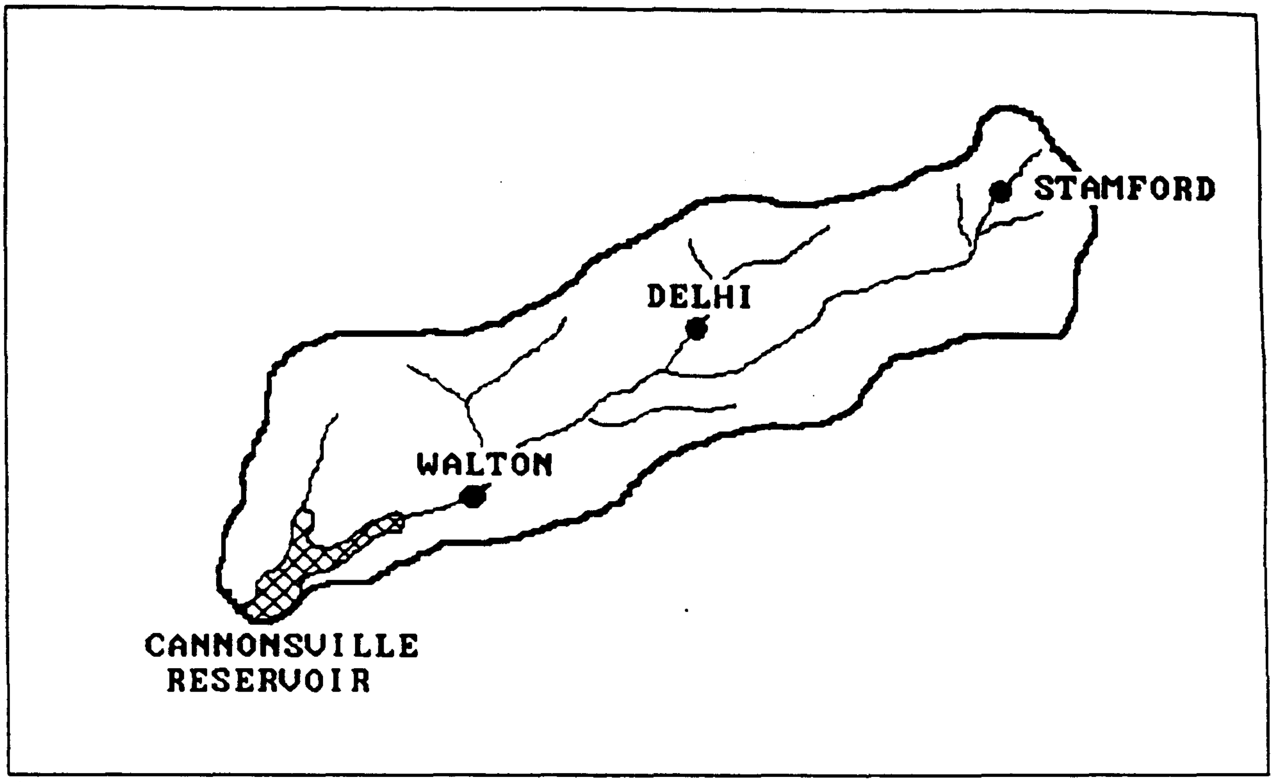


Figure C-1. West Branch Delaware River Watershed.

The 850 km^2 watershed, which is shown in Figure C-1, is in a dairy farming area in southeast New York which consists of 30% agricultural, 67% forested and 2% urban land uses. The river empties into Cannonsville Reservoir, which is a water supply source for the City of New York.

The model was run for the four-year period using daily precipitation and temperature records from the U.S. Environmental Data and Information service weather station at Walton, NY. To test the usefulness of the default parameters presented previously, no attempt was made to calibrate the model. No water quality data from the watershed were used to estimate parameters. All transport and chemical parameters were obtained by the general procedures described in the Appendix B.

Water Quality Observations

Continuous streamflow records were available from a U.S. Geological Survey gauging station at Walton, NY. Nutrient and sediment data were collected, analyzed and summarized by the N.Y. State Department of Environmental Conservation (Brown et al., 1985). During base flow conditions, samples were collected at approximately one-week intervals. During storm events, samples were collected at 2-4 hour intervals during hydrograph rise and at 6-8 hour intervals in the 2-3 days following flow peak. More frequent sampling was carried out during major snowmelt events. Total and dissolved phosphorus and sediment (suspended solids) data were collected from March, 1980 through March, 1982. The sampling periods for dissolved and total nitrogen were less extensive: March, 1980 - September, 1981 and January, 1981 - September, 1981, respectively.

Mass fluxes were computed by multiplying sediment or nutrient concentrations in a sample by "a volume of water determined by numerically integrating flow over the period of time from half of the preceding sampling time interval through half of the following sampling time interval" (Brown et al., 1985).

Watershed Data

Land Uses. The parameters needed for the agricultural and forest source areas were estimated from a land use sampling procedure similar to that described by Haith & Tubbs (1981). U.S. Geological Survey 1:24,000 topographic maps of the watershed were overlain by land use maps derived from 1971-1974 aerial photography. The maps were then overlain by a grid with 1-ha cells which was the basis of the sampling procedure. The land uses were divided into two general categories: forest and agriculture. Forest areas were subdivided into forest brushland and mature forest, and agricultural areas were subdivided into cropland, pasture and inactive agriculture. A random sample of 500 cells was taken, stratified over the two major land uses to provide more intense sampling of agricultural areas (390 samples vs. 110 for forest).

For each agricultural sample, the following were recorded: land use (cropland, pasture or inactive), soil type and length and gradient of the slope of the field in which the 1-ha sample was located. Crops were separated into two categories, corn or hay, since these two crops make up 99% of the county cropland.

Barnyard areas were identified from examination of conservation plans for 30 watershed dairy farm barnyards. Average earthen and roof drainage areas were 0.1306 ha and 0.0369 ha, respectively. These values were assumed representative of the watershed's 245 barnyards, producing total earth and roof drainage areas of 32 and 9 ha, respectively.

Urban land uses (low-density residential, commercial and industrial) were calculated from Delaware County tax maps. The impervious portions of these areas were 16%, 54% and 34% for residential, commercial and industrial land uses, respectively.

Runoff Curve Numbers. In forest areas, curve numbers were selected by soil type, assuming "good" hydrologic condition. Agricultural curve numbers were selected based on soil type, crop, management practice (e.g., strip cropping) and hydrologic condition. All pasture, hay and corn-hay rotations were assumed to be in good condition. Inactive agricultural areas were assumed to be the same as pasture. Corn grown in continuous rotation was considered in poor condition. Cropland breakdown into hay, continuous corn and rotated corn was determined from county data assembled by Soil Conservation Service (1976) and confirmed from Bureau of the Census (1980).

Rural source areas and curve numbers are listed in Table C-1. These areas were subsequently aggregated for the GWLF input files into the large areas given in Table C-2. Urban and barnyard areas are also given in Table C-2. Curve numbers are area-weighted averages for each source area.

Erosion and Sediment Parameters. Data required for estimation of soil loss parameters for logging sites were obtained from a forestry survey (Slavicek, 1980). Logging areas were located from a 1979 aerial survey. Transects of the logging roads at these sites were measured for soil loss parameters K_k, $(LS)_k$, C_k and P_k and from this information an average K_k $(LS)_k$ C_k P_k value was calculated.

Soil erodibility factors (K_k) for agricultural land were obtained from the Soil Conservation Service. Cove factors (C) were selected Table B-10 based on several assumptions. For corn, the assumptions were tha all residues are removed from the fields (91% of the corn in the county is used for silage (Bureau of the Census, 1980)), and all fields are spring turn-plowed and in the high productivity class (Knoblauch, 1976) A moderate productivity was assumed for hay (Knoblauch, 1976). Supporting practice factors of P = 1 were used for all source areas except strip crop corn. Area-weighted K_k $(LS)_k$ C_k P_k values are given in Tabl C-2. Coefficients for daily rainfall erosivity were selected from Table B-13 for Zone 31 (Figure B-1) . A watershed sediment delivery ratio of 0.065 was determined from Figure B-2.

Source Area	Soil Hydrologic Group	Area(ha)	Curve Number[a]
Continuous corn	B	414	81
	C	878	88
Rotated corn	B	620	78
	C	1316	85
Strip crop corn	C	202	82
Hay	B	2319	72
	C	10690	81
	D	76	85
Pasture	B	378	61
	C	4639	74
	D	76	80
Inactive agriculture	B	328	61
	C	3227	74
	D	126	80
Forest brushland	B	3118	48
	C	24693	65
	D	510	73
Mature forest	B	510	55
	C	27851	70

a/ Antecedent moisture condition 2 ($CN2_K$)

Table C-1. **Areas and Curve Numbers for Agricultural and Forest Runoff Sources for West Branch Delaware River Basin.**

Land Use	Area(ha)	Curve Number[a]	Erosion Product[b]
Corn	3430	83.8	0.214
Hay	13085	79.4	0.012
Pasture	5093	73.1	0.016
Inactive Agriculture	3681	73.1	0.017
Barnyards	41	92.2	–
Forest	56682	66.5	–
Logging Trails	20	–	0.217
Residential (Low Density)			
Impervious	104	98.0	–
Pervious	546	74.0	–
Commercial			
Impervious	49	98.0	–
Pervious	41	74.0	–
Industrial			
Impervious	34	98.0	–
Pervious	67	74.0	–

[a] Antecedent moisture condition 2 ($CN2_k$).

[b] $K_k \ (LS)_k \ C_k \ P_k$

Table C-2. Aggregated Runoff Source Areas in West Branch Delaware River Basin.

Land Use	Area(ha)	Cover Coefficient May-Oct	Cover Coefficient Nov-Apr
Corn	3430	1.0	0.3
Hay	13085	1.0	1.0
Pasture	5093	1.0	1.0
Inactive Agriculture	3681	1.0	1.0
Forest	56682	1.0	0.3
Logging	20	0.3	0.3
Barn Yards	41	0.3	0.3
Residential	650	0.84	0.84
Commercial	90	0.46	0.46
Industrial	101	0.66	0.66
Watershed Weighted Mean	82873	1.00	0.49

Table C-3. Evapotranspiration Cover Coefficients for West Branch Delaware River Basin.

Other Transport Parameters. For purpose of curve number and evapotranspiration cover coefficient selection, the growing season was assumed to correspond to months during which mean air temperature is at least 10°C (May-October). Cover coefficients were selected from Table B-8 and are listed in Table C-3 along with the area-weighted watershed values. An average groundwater recession constant of $r = 0.1$ was determined from analysis of 30 hydrograph recessions from the period 1971 - 1978. The seepage constant (s) was assumed to be zero, and the default value of 10 cm was used for unsaturated zone available soil moisture capacity U^*.

Nutrient Concentrations and Accumulation Rates. Using the soil nutrient values given in Figures B-3 and B-4 and the previously suggested enrichment ratio of 2.0 produced sediment nutrient concentrations of 3000 mg/kg nitrogen and 1300 mg/kg phosphorus. Rural dissolved nutrient concentrations were selected from Tables B-15 and B-16. Manure is spread on corn land in the watershed and hence the manured land concentrations were used for corn land runoff in snowmelt months (January - March). Inactive agricultural land was assumed to have nutrient concentrations midway between pasture and forest values. Urban nutrient accumulation rates from Table B-17 were used, with "Central business district" values used for commercial land.

Septic System Parameters. The default values for nutrient loads and plant uptake given in Table B-18 were used to model septic systems. The population served by each type of septic system was estimated by determining the percentage of the total number of systems falling within each class and multiplying by the year-round and seasonal (June - August) unsewered populations in the watershed. Table C-4 summarizes the population data for septic systems.

System Type	Percent of Total Population	Population Served	
		Year-round	Seasonal[a/]
Normal	86	7572	1835
Short-circuited	1	88	21
Ponded	10	881	213
Direct discharge	3	264	64

[a/] June - August

Table C-4. Estimated Populations Served by Different Septic System Types in West Branch Delaware River Basin.

The year-round unsewered population estimate for the watershed was based on 1980 Census data. These data were also used to determine the average number of people per household and the number of housing units used on a part-time basis. The seasonal population was then calculated by assuming the number of people per household was the same for seasonal and year-round residents.

A range of values for the current (1991) percentage of each type of system was supplied by the New York City Department of Environmental Protection (Personal Communication, J. Kane, New York City Department of Environmental Protection). A estimate of the percentages for the study period was determined by comparing the range of current values with the percentages from a survey of a neighboring area of Delaware County with construction practices and code enforcement similar to the West Branch Delaware River Watershed at the time of the study (Personal Communication, A. Lemley, Cornell University).

Point Sources. Point sources of nutrients are dissolved loads from five municipal and two industrial wastewater treatment plants. These inputs are 3800 kg/mo nitrogen and 825 kg/mo phosphorus (Brown & Rafferty, 1980; Dickerhoff, 1981).

Complete data inputs for the validation simulation run are given in Appendix D.

Validation Results

The GWLF streamflow predictions are compared with observations in Figure C-2. It is apparent that although the model mirrors the timing of observed streamflow, predictions for any particular month may have substantial errors. Accuracy is poorest for low flows, when predicted streamflows are essentially zero due to the very simple lumped parameter groundwater model.

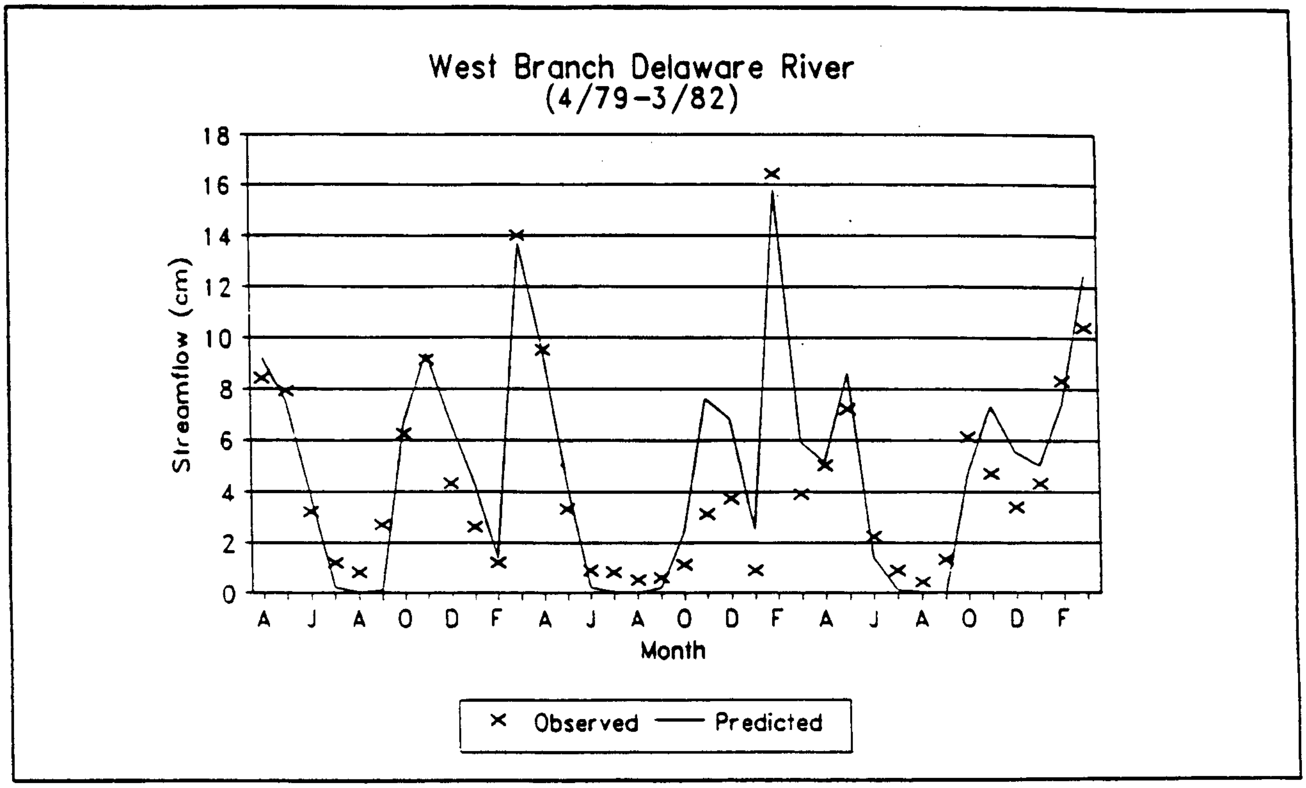


Figure C-2. Observed and Predicted Monthly Streamflow.

Model predictions and observations for total phosphorus and nitrogen are compared in Figures C-3 and C-4. Both sets of predictions match the variations in observations but under-predict the February, 1981 peak values by 35% and 26% for phosphorus and nitrogen, respectively. A quantitative summary of the comparisons of predictions with observations is given in Table C-5. Monthly mean predictions are within 10% of observation means for five of the six model outputs. The predicted mean total nitrogen flux is 73% of the observed mean. No coefficient of determination (R^2) is less than 0.88, indicating that the model explains at least 88% of the observed monthly variation in streamflow, sediment yield and nutrient fluxes.

Mean annual nutrient loads from each source for the four-year simulation period are provided in Table C-6. It is apparent that cropland runoff is a major source of streamflow nitrogen and phosphorus. Groundwater discharge is the largest source of nitrogen, accounting for 41% of dissolved and 36% of total nitrogen loads. Point sources constitute 11% of total nitrogen and 20% of total phosphorus. Septic tank drainage provides nearly as much nitrogen as point sources, but is a minor phosphorus source.

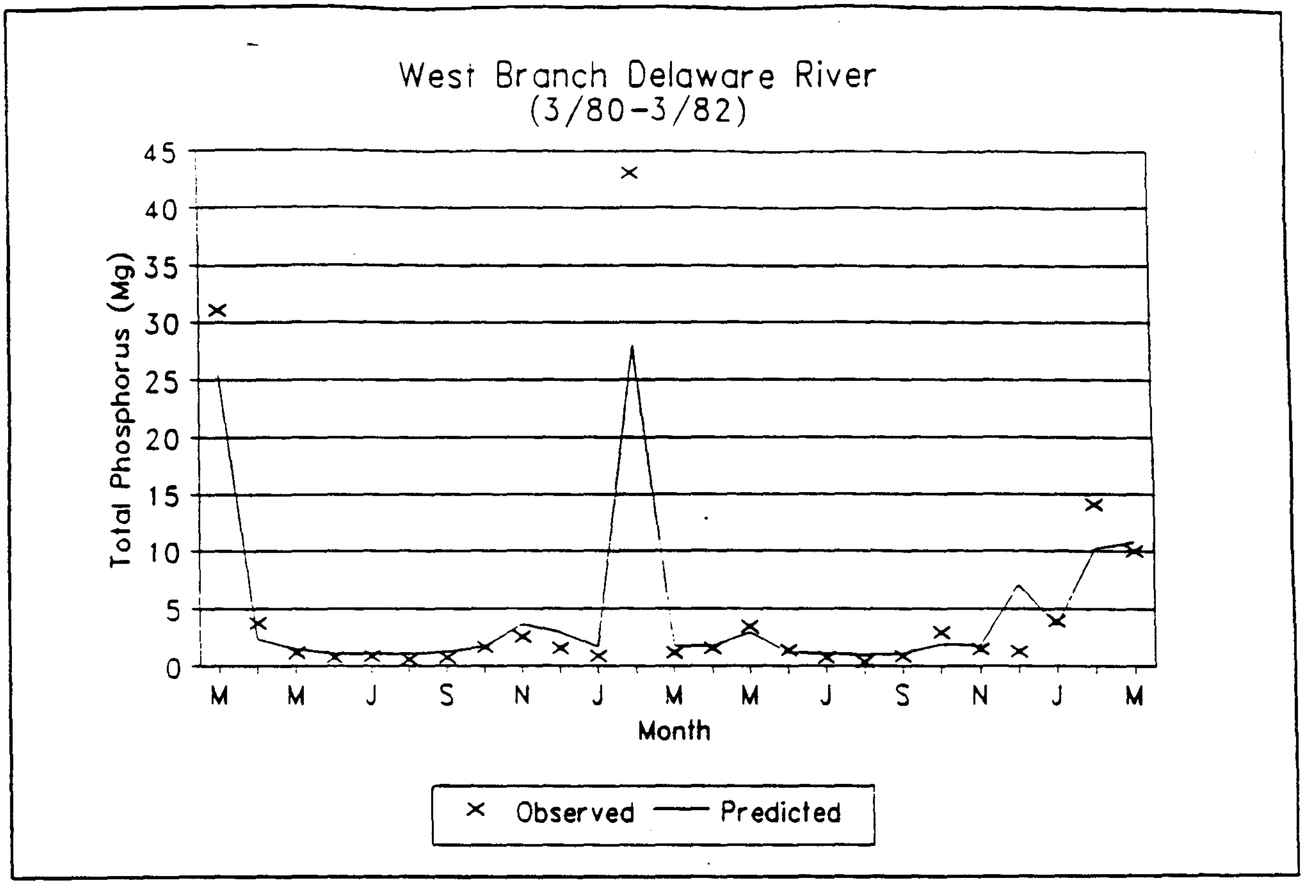


Figure C-3. Observed and Predicted Total Phosphorus in Streamflow.

Constituent	Validation Period	Monthly Means Predicted	Monthly Means Observed	Coefficient of Determination (R^2)
Streamflow (cm)	4/79-3/82	4.9	4.5	0.88
Sediment (1000 Mg)	3/80-3/82	1.6	1.7	0.95
Nitrogen (Mg)				
Dissolved	3/80-9/81	27.8	27.8	0.94
Total	1/81-9/81	32.9	44.8	0.99
Phosphorus (Mg)				
Dissolved	3/80-3/82	2.6	2.4	0.95
Total	3/80-3/82	4.7	5.2	0.95

Table C-5. Comparison of GWLF Predictions and Observations for the West Branch Delaware River Watershed.

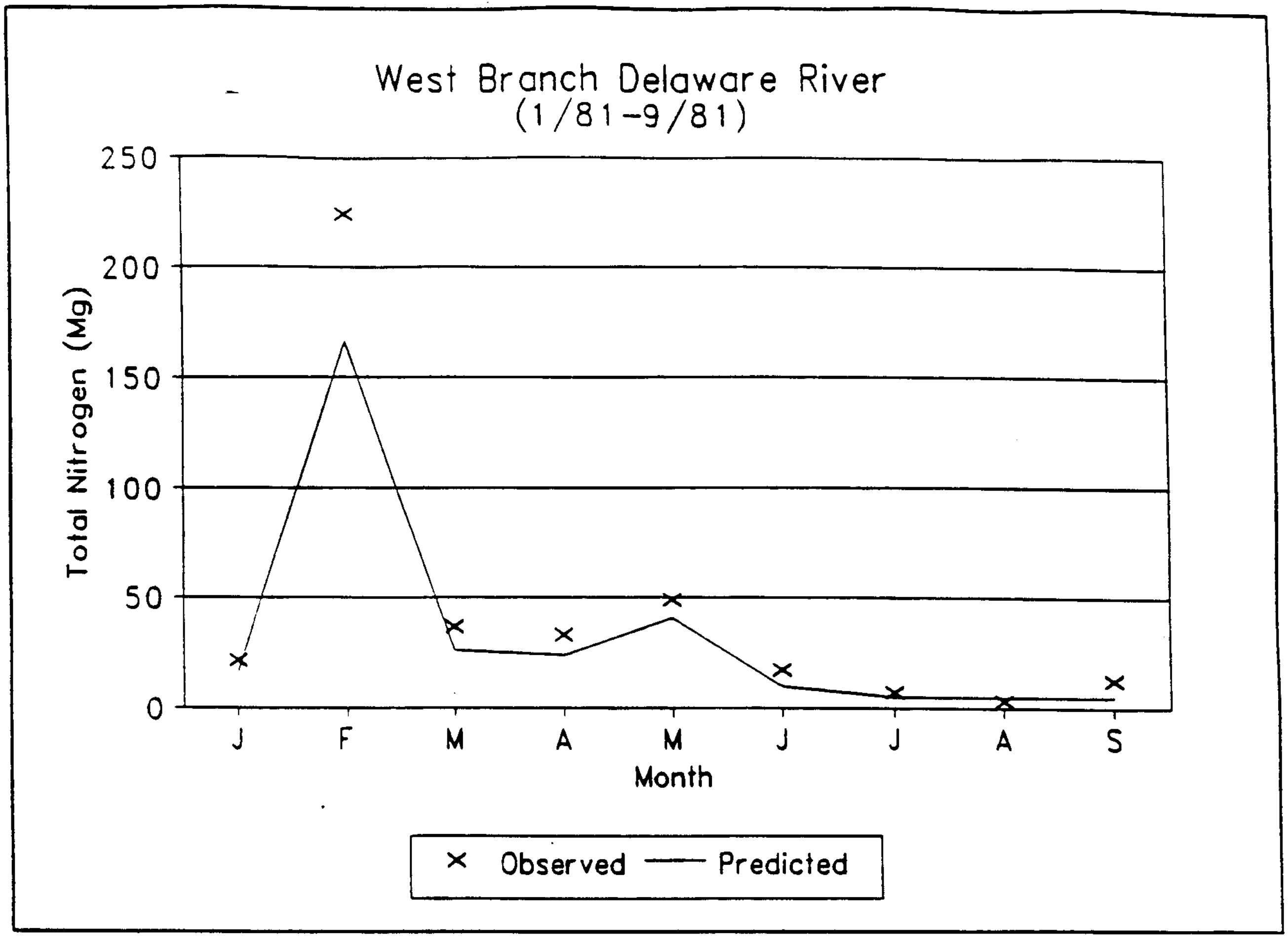


Figure C-4. Observed and Predicted Total Nitrogen in Streamflow.

Conclusions

The watershed loading functions model GWLF is based on simple runoff, sediment and groundwater relationships combined with empirical chemical parameters. The model is unique in its ability to estimate monthly nutrient fluxes in streamflow without calibration. Validation studies in a large New York watershed indicated that the model possesses a high degree of predictive accuracy. Although better results could perhaps be obtained by more detailed chemical simulation models, such models have substantially greater data and computational requirements and must be calibrated from water quality sampling data.

The GWLF model has several limitations. Peak monthly nutrient fluxes were underestimated by as much as 35%. Since nutrient chemistry is not modeled explicitly, the model cannot be used to estimate the effects of fertilizer management or urban storm water storage and treatment. The model has only been validated for a largely rural watershed in which agricultural runoff and groundwater discharge provided most of the nutrient load. Although the urban runoff component is based on well-known relationships which have been used previously in such models as STORM and SWMM, GWLF performance in more urban watersheds is uncertain.

Source	Nitrogen (Mg) Dissolved	Total	Phosphorus (Mg) Dissolved	Total
Runoff				
Corn	52.9	84.6	7.8	21.5
Hay	48.6	55.4	2.6	5.5
Pasture	13.2	16.7	1.1	2.6
Inactive Agriculture	5.1	7.8	0.4	1.6
Forest & logging	5.9	6.1	0.2	0.3
Barn yards	4.3	4.3	0.8	0.8
Urban	–	2.8	–	0.3
Groundwater, Point Sources, & Septic Systems				
Groundwater Discharge	149.6	149.6	5.7	5.7
Point sources	45.6	45.6	9.9	9.9
Septic systems	38.1	38.1	1.1	1.1
Watershed Total	363.4	411.1	29.6	48.3

Table C-6. Mean Annual Nutrient Loads Estimated from GWLF for the West Branch Delaware River Watershed: 4/78 - 3/82.

APPENDIX D: DATA AND OUTPUT LISTINGS FOR VALIDATION STUDY (EXAMPLE 1)

The first listing in this appendix is the set of sequential data input files **TRANSPRT.DAT**, **NUTRIENT.DAT** and **WEATHER.DAT** used in the validation study and Example 1. The first two files are constructed by selecting the appropriate option from GWLF menus. The weather file is arranged by months (April - March, in this application) with the first entry for each month being the number of days in the month, and subsequent entries being temperature (°C) and precipitation (cm) for each day. Only a partial listing of **WEATHER.DAT** is given. The next listings are the text files for the transport and nutrient data (**TRANSPRT.TXT** and **NUTRIENT.TXT**). The remaining listings are text files of the several program outputs (**SUMMARY.TXT** and **MONTHLY.TXT**).

TRANSPRT.DAT

```
7,6
.1,0,10,0,0,.065,10
0
0
0
0
0          daylight
"APR",.49,13.1,0,.25
"MAY",1,14.3,1,.25
"JUNE",1,15,1,.25
"JULY",1,14.6,1,.25
"AUG",1,13.6,1,.25
"SEPT",1,12.3,1,.25
"OCT",1,10.9,1,.06
"NOV",.49,9.7,0,.06
"DEC",.49,9,0,.06
"JAN",.49,9.3,0,.06
"FEB",.49,10.4,0,.06
"MAR",.49,11.7,0,.06
"CORN",3430,83.8,.214
"HAY",13085,79.4,.012
"PASTURE",5093,73.1,.016
"INACTIVE",3681,73.1,.017
"FOREST",56682,66.5,0
"LOGGING",20,0,.217
"BARN YARDS",41,92.2,0
"RES-imperv",104,98,0
"RES-perv",546,74,0
"COMM-imperv",49,98,0
"COMM-perv",41,74,0
"INDUS-imperv",34,98,0
"INDUS-perv",67,74,0
```

NUTRIENT.DAT

```
3000,1300,.34,.013
1,10,12
2.9,.26
2.8,.15
3,.25
1.6,.13
.19,.006
0,0
29.3,5.1
0.045,0.0045
0.012,0.0016
0.101,0.0112
0.012,0.0019
0.101,0.0112
0.012,0.0019
12.2,1.9
3800,825
3800,825
3800,825
3800,825
3800,825
3800,825
3800,825
3800,825
3800,825
3800,825
3800,825
3800,825
1
7572,881,88,264
7572,881,88,264
9407,1094,109,328
9407,1094,109,328
9407,1094,109,328
7572,881,88,264
7572,881,88,264
7572,881,88,264
7572,881,88,264
7572,881,88,264
7572,881,88,264
7572,881,88,264
12,2.5,1.6,.4
```

WEATHER.DAT

```
30
11,.2
2,.4
-3,.1
2,0
3,1
4,0
9,.4
2,.1
2,.1
4,0
12,.1
10,.6
12,0
5,.1
2,.1
5,0
4,0
5,.1
7,0
8,1.3
4,.4
6,.1
4,0
6,0
7,0
8,0
9,0
8,0
7,0
5,.1
31
-1,0
6,0
6,0
5,0
7,.3
6,1.3
11,.6
9,0
15,.8
10,.2
15,0
13,0
16,0
14,0
12,.5
11,.4
11,.8
14,.4
17,.2
•
•
•
```

TRANSPRT.TXT

```
TRANSPRT DATA

LAND USE        AREA(ha)        CURVE NO        KLSCP
CORN              3430.           83.8           0.21400
HAY              13085.           79.4           0.01200
PASTURE           5093.           73.1           0.01600
INACTIVE          3681.           73.1           0.01700
FOREST           56682.           66.5           0.00000
LOGGING             20.            0.0           0.21700
BARN YARDS          41.           92.2           0.00000
RES-imperv         104.           98.0           0.00000
RES-perv           546.           74.0           0.00000
COMM-imperv         49.           98.0           0.00000
COMM-perv           41.           74.0           0.00000
INDUS-imperv        34.           98.0           0.00000
INDUS-perv          67.           74.0           0.00000

MONTH    ET CV()    DAY HRS    GROW. SEASON    EROS. COEF
APR       0.490      13.1       0                .25
MAY       1.000      14.3       1                .25
JUNE      1.000      15         1                .25
JULY      1.000      14.6       1                .25
AUG       1.000      13.6       1                .25
SEPT      1.000      12.3       1                .25
OCT       1.000      10.9       1                .06
NOV       0.490      9.7        0                .06
DEC       0.490      9          0                .06
JAN       0.490      9.3        0                .06
FEB       0.490      10.4       0                .06
MAR       0.490      11.7       0                .06

ANTECEDENT RAIN+MELT FOR DAY -1 TO DAY -5
 0         0         0         0         0
INITIAL UNSATURATED STORAGE (cm) -    10
INITIAL SATURATED STORAGE (cm)    -   0
RECESSION COEFFICIENT (1/day)     -   .1
SEEPAGE COEFFICIENT (1/day)       -   0
INITIAL SNOW (cm water)           -   0
SEDIMENT DELIVERY RATIO           -  0.067
UNSAT AVAIL WATER CAPACITY (cm)   -   10
```

NUTRIENT.TXT

```
                    NUTRIENT DATA

RURAL LAND USE     DIS.NITR IN RUNOFF(mg/l)     DIS.PHOS IN RUNOFF(mg/l)
CORN                     2.9                          .26
HAY                      2.8                          .15
PASTURE                  3                            .25
INACTIVE                 1.6                          .13
FOREST                   .19                          .006
LOGGING                  0                            0
BARN YARDS               29.3                         5.1
```

NUTRIENT CONCENTRATIONS IN RUNOFF FROM MANURED AREAS

LAND USE	NITROGEN(mg/l)	PHOSPHORUS(mg/l)
CORN	12.2	1.9

URBAN LAND USE	NITR.BUILD-UP(kg/ha-day)	PHOS.BUILD-UP(kg/ha-day)
RES-imperv	.045	.0045
RES-perv	.012	.0016
COMM-imperv	.101	.0112
COMM-perv	.012	.0019
INDUS-imperv	.101	.0112
INDUS-perv	.012	.0019

MONTH	POINT SOURCE NITR.(kg)	POINT SOURCE PHOS.(kg)
APR	3800	825
MAY	3800	825
JUNE	3800	825
JULY	3800	825
AUG	3800	825
SEPT	3800	825
OCT	3800	825
NOV	3800	825
DEC	3800	825
JAN	3800	825
FEB	3800	825
MAR	3800	825

NITROGEN IN GROUNDWATER (mg/l):	0.340
PHOSPHORUS IN GROUNDWATER (mg/l):	0.013
NITROGEN IN SEDIMENT (mg/kg):	3000
PHOSPHORUS IN SEDIMENT (mg/kg):	1300

MANURE SPREADING JAN THRU MAR

SEPTIC SYSTEMS

	POPULATION SERVED			
MONTH	NORMAL SYSTEMS	PONDING SYSTEMS	SHORT-CIRCUIT SYSTEMS	DISCHARGE SYSTEMS
APR	7572	881	88	264
MAY	7572	881	88	264
JUNE	9407	1094	109	328
JULY	9407	1094	109	328
AUG	9407	1094	109	328
SEPT	7572	881	88	264
OCT	7572	881	88	264
NOV	7572	881	88	264
DEC	7572	881	88	264
JAN	7572	881	88	264
FEB	7572	881	88	264
MAR	7572	881	88	264

PER CAPITA TANK EFFLUENT NITROGEN (g/day) - 12
PER CAPITA TANK EFFLUENT PHOSPHORUS (g/day) - 2.5
PER CAPITA GROWING SEASON NITROGEN UPTAKE (g/day) - 1.6
PER CAPITA GROWING SEASON PHOSPHORUS UPTAKE (g/day) - .4

SUMMARY.TXT

```
W. Branch Delaware River 4/78-3/82     4 -year means

        PRECIP        EVAPOTRANS  GR.WAT.FLOW  RUNOFF        STREAMFLOW
            ----------------(cm)--------------------------------
APR       9.6            1.9         6.5          0.3           6.7
MAY       9.8            7.5         5.3          0.3           5.6
JUNE      8.3            9.7         1.8          0.0           1.8
JULY      8.6           11.3         0.1          0.0           0.2
AUG      10.4            9.2         1.2          0.9           2.0
SEPT     11.6            5.8         0.1          0.1           0.2
OCT      11.5            3.1         4.3          0.1           4.4
NOV       8.2            0.7         6.6          0.4           7.0
DEC       8.0            0.2         5.6          0.4           6.0
JAN       8.1            0.1         5.0          1.1           6.1
FEB       8.5            0.2         5.7          1.8           7.4
MAR       9.8            0.8        10.9          2.4          13.3
--------------------------------------------------------------------
ANNUAL 112.3            50.7        53.1          7.8          60.8

        EROSION   SEDIMENT  DIS.NITR  TOT.NITR  DIS.PHOS  TOT.PHOS
        ----(1000 Mg)----       ------------(Mg)-----------------
APR      29.2        0.0       30.7      31.1       1.9       2.0
MAY      35.7        0.2       26.9      27.7       1.8       2.1
JUNE     23.5        0.0       10.7      10.9       1.1       1.2
JULY     28.1        0.0        4.9       5.2       1.0       1.0
AUG      45.8        1.2       17.2      21.0       1.7       3.2
SEPT     45.0        0.0        6.2       6.6       1.1       1.1
OCT      11.2        0.1       21.3      21.8       1.6       1.7
NOV       6.3        0.9       33.3      36.1       2.1       3.2
DEC       0.8        1.1       28.9      32.3       1.9       3.3
JAN       0.4        1.1       41.4      45.0       3.6       5.1
FEB       0.5        4.4       55.4      68.8       4.9      10.6
MAR       3.7        6.0       86.6     104.8       7.0      14.8
--------------------------------------------------------------------
ANNUAL  230.4       15.0      363.4     411.0      29.6      49.3

SOURCE         AREA   RUNOFF  EROSION  DIS.NITR TOT.NITR DIS.PHOS TOT.PHOS
               (ha)   (cm)    (Mg/ha)   -------------(Mg)-----------
CORN           3430.   18.03   47.43     52.92    84.64     7.78    21.52
HAY           13085.   13.27    2.66     48.60    55.39     2.60     5.54
PASTURE        5093.    8.65    3.55     13.22    16.74     1.10     2.63
INACTIVE       3681.    8.65    3.77      5.10     7.80     0.41     1.59
FOREST        56682.    5.47    0.00      5.89     5.89     0.19     0.19
LOGGING          20.    0.00   48.10      0.00     0.19     0.00     0.08
BARN YARDS       41.   36.11    0.00      4.34     4.34     0.76     0.76
RES-imperv      104.   74.11    0.00      0.00     0.86     0.00     0.09
RES-perv        546.    9.20    0.00      0.00     0.29     0.00     0.04
COMM-imperv      49.   74.11    0.00      0.00     0.91     0.00     0.10
COMM-perv        41.    9.20    0.00      0.00     0.02     0.00     0.00
INDUS-imperv     34.   74.11    0.00      0.00     0.63     0.00     0.07
INDUS-perv       67.    9.20    0.00      0.00     0.04     0.00     0.01
GROUNDWATER                             149.58   149.58     5.72     5.72
POINT SOURCE                             45.60    45.60     9.90     9.90
SEPTIC SYSTEMS                           38.13    38.13     1.11     1.11
--------------------------------------------------------------------------
TOTAL                                   363.37   411.05    29.57    49.34
```

MONTHLY.TXT -

```
W. Branch Delaware River 4/78-3/82   YEAR  1

         PRECIP        EVAPOTRANS   GR.WAT.FLOW  RUNOFF        STREAMFLOW
            ----------------(cm)--------------------------------
APR       5.2            1.7           3.1          0.0          3.1
MAY       7.9            7.4           2.1          0.0          2.1
JUNE     10.5            9.7           1.8          0.0          1.8
JULY     10.8           10.9           0.3          0.0          0.4
AUG      17.0           10.4           4.6          3.4          8.1
SEPT      7.6            5.5           0.4          0.1          0.4
OCT      11.6            3.1           3.9          0.0          3.9
NOV       4.7            0.7           3.7          0.1          3.8
DEC      12.6            0.2           5.2          0.0          5.2
JAN      19.1            0.2           8.7          3.8         12.6
FEB       4.0            0.1           4.6          0.5          5.1
MAR      10.9            1.1          16.5          4.6         21.0
-------------------------------------------------------------------
YEAR    121.9           50.9          54.9         12.6         67.4

         EROSION   SEDIMENT  DIS.NITR  TOT.NITR  DIS.PHOS  TOT.PHOS
         ----(1000 Mg)----          -----------(Mg)----------------
APR        8.3        0.0      14.9      15.0       1.3       1.3
MAY       13.3        0.0      11.3      11.5       1.1       1.2
JUNE      29.3        0.0      10.8      11.0       1.2       1.2
JULY      39.4        0.0       5.8       6.1       1.0       1.0
AUG      109.6        4.7      54.9      69.5       3.8      10.0
SEPT      35.4        0.0       6.8       6.9       1.1       1.1
OCT       10.3        0.0      17.8      18.1       1.4       1.4
NOV        1.4        0.0      18.2      18.4       1.4       1.4
DEC        1.8        0.0      22.1      22.3       1.5       1.5
JAN        0.0        3.8     100.4     112.2       8.9      13.9
FEB        0.0        0.2      32.7      33.5       2.8       3.1
MAR        5.0        7.7     139.6     163.2      11.2      21.3
-------------------------------------------------------------------
YEAR     253.8       16.5     435.3     487.5      36.6      58.3

SOURCE          AREA   RUNOFF   EROSION  DIS.NITR TOT.NITR DIS.PHOS TOT.PHOS
                (ha)   (cm)     (Mg/ha)   -------------(Mg)-----------
CORN            3430.  24.70    52.26     81.18   116.13    12.18    27.33
HAY            13085.  19.27     2.93     70.59    78.06     3.78     7.02
PASTURE         5093.  13.86     3.91     21.18    25.06     1.76     3.45
INACTIVE        3681.  13.86     4.15      8.16    11.14     0.66     1.95
FOREST         56682.   9.81     0.00     10.57    10.57     0.33     0.33
LOGGING           20.   0.00    52.99      0.00     0.21     0.00     0.09
BARN YARDS        41.  44.22     0.00      5.31     5.31     0.92     0.92
RES-imperv       104.  82.95     0.00      0.00     0.86     0.00     0.09
RES-perv         546.  14.52     0.00      0.00     0.30     0.00     0.04
COMM-imperv       49.  82.95     0.00      0.00     0.90     0.00     0.10
COMM-perv         41.  14.52     0.00      0.00     0.02     0.00     0.00
INDUS-imperv      34.  82.95     0.00      0.00     0.63     0.00     0.07
INDUS-perv        67.  14.52     0.00      0.00     0.04     0.00     0.01
GROUNDWATER                              154.61   154.61     5.91     5.91
POINT SOURCE                              45.60    45.60     9.90     9.90
SEPTIC SYSTEMS                            38.10    38.10     1.11     1.11
----------------------------------------------------------------------------
TOTAL                                    435.30   487.55    36.58    58.33
```

W. Branch Delaware River 4/78-3/82 YEAR 2

	PRECIP	EVAPOTRANS	GR.WAT.FLOW	RUNOFF	STREAMFLOW
	(cm)				
APR	11.0	1.8	8.5	0.7	9.2
MAY	15.3	7.6	6.8	0.6	7.5
JUNE	4.2	9.6	3.8	0.0	3.8
JULY	7.2	11.5	0.2	0.0	0.2
AUG	9.2	7.6	0.0	0.0	0.0
SEPT	14.3	6.0	0.0	0.1	0.1
OCT	11.2	3.4	6.7	0.1	6.7
NOV	13.5	0.9	8.6	0.8	9.4
DEC	5.0	0.4	6.7	0.0	6.7
JAN	3.7	0.2	4.3	0.0	4.3
FEB	4.0	0.1	1.4	0.0	1.4
MAR	14.8	0.7	10.7	3.0	13.7
YEAR	113.4	49.8	57.6	5.4	63.0

	EROSION	SEDIMENT	DIS.NITR	TOT.NITR	DIS.PHOS	TOT.PHOS
	(1000 Mg)		(Mg)			
APR	35.1	0.2	43.4	44.2	2.6	2.8
MAY	66.9	0.5	37.6	39.3	2.4	3.1
JUNE	11.2	0.0	17.2	17.3	1.3	1.4
JULY	15.4	0.0	4.9	5.1	0.9	1.0
AUG	19.1	0.0	4.4	4.6	0.9	1.0
SEPT	64.7	0.1	6.5	7.0	1.1	1.2
OCT	8.2	0.0	27.9	28.2	1.7	1.8
NOV	21.0	2.6	45.2	53.3	2.7	6.1
DEC	0.7	0.0	27.6	27.9	1.7	1.7
JAN	1.7	0.0	18.9	19.0	1.4	1.4
FEB	0.0	0.0	10.2	10.3	1.2	1.2
MAR	8.6	13.0	99.0	138.5	8.5	25.5
YEAR	252.7	16.4	342.6	394.6	26.4	48.1

SOURCE	AREA (ha)	RUNOFF (cm)	EROSION (Mg/ha)	DIS.NITR	TOT.NITR	DIS.PHOS	TOT.PHOS
				(Mg)			
CORN	3430.	15.22	52.02	37.28	72.08	5.26	20.34
HAY	13085.	10.54	2.92	38.60	46.05	2.07	5.29
PASTURE	5093.	6.11	3.89	9.33	13.19	0.78	2.45
INACTIVE	3681.	6.11	4.13	3.60	6.56	0.29	1.58
FOREST	56682.	3.26	0.00	3.51	3.51	0.11	0.11
LOGGING	20.	0.00	52.75	0.00	0.21	0.00	0.09
BARN YARDS	41.	33.71	0.00	4.05	4.05	0.70	0.70
RES-imperv	104.	74.86	0.00	0.00	0.88	0.00	0.09
RES-perv	546.	6.62	0.00	0.00	0.28	0.00	0.04
COMM-imperv	49.	74.86	0.00	0.00	0.93	0.00	0.10
COMM-perv	41.	6.62	0.00	0.00	0.02	0.00	0.00
INDUS-imperv	34.	74.86	0.00	0.00	0.64	0.00	0.07
INDUS-perv	67.	6.62	0.00	0.00	0.03	0.00	0.01
GROUNDWATER				162.40	162.40	6.21	6.21
POINT SOURCE				45.60	45.60	9.90	9.90
SEPTIC SYSTEMS				38.21	38.21	1.12	1.12
TOTAL				342.59	394.64	26.44	48.10

W. Branch Delaware River 4/78-3/82 YEAR 3

	PRECIP	EVAPOTRANS	GR.WAT.FLOW	RUNOFF	STREAMFLOW
	(cm)				
APR	11.9	2.1	9.3	0.2	9.5
MAY	3.2	7.6	4.3	0.0	4.3
JUNE	10.4	9.1	0.2	0.0	0.2
JULY	9.5	11.5	0.0	0.0	0.0
AUG	9.9	10.3	0.0	0.0	0.0
SEPT	10.7	6.3	0.0	0.2	0.2
OCT	10.0	3.0	2.2	0.2	2.4
NOV	8.8	0.5	6.7	0.9	7.6
DEC	6.3	0.1	6.2	0.6	6.8
JAN	2.8	0.0	2.4	0.1	2.5
FEB	16.8	0.6	10.7	5.1	15.8
MAR	4.3	0.8	5.9	0.0	5.9
YEAR	104.6	52.0	47.8	7.4	55.2

	EROSION	SEDIMENT	DIS.NITR	TOT.NITR	DIS.PHOS	TOT.PHOS
	(1000 Mg)		(Mg)			
APR	45.5	0.0	40.9	41.2	2.2	2.3
MAY	6.7	0.0	19.2	19.3	1.4	1.4
JUNE	38.2	0.0	5.4	5.7	1.0	1.0
JULY	37.6	0.0	4.5	4.7	1.0	1.0
AUG	41.7	0.0	5.2	5.4	1.0	1.0
SEPT	36.6	0.1	7.1	7.5	1.1	1.2
OCT	15.9	0.1	16.3	17.0	1.5	1.7
NOV	0.5	0.8	40.3	43.1	2.5	3.6
DEC	0.2	0.6	33.9	35.8	2.1	2.9
JAN	0.0	0.0	15.6	15.8	1.5	1.6
FEB	2.1	13.0	126.8	166.2	11.1	28.0
MAR	0.7	0.0	25.7	26.0	1.7	1.7
YEAR	225.7	14.7	340.9	387.6	28.1	47.5

SOURCE	AREA (ha)	RUNOFF (cm)	EROSION (Mg/ha)	DIS.NITR	TOT.NITR	DIS.PHOS	TOT.PHOS
				(Mg)			
CORN	3430.	17.55	46.48	48.63	79.72	7.06	20.53
HAY	13085.	12.74	2.61	46.69	53.34	2.50	5.38
PASTURE	5093.	8.17	3.47	12.48	15.93	1.04	2.54
INACTIVE	3681.	8.17	3.69	4.81	7.46	0.39	1.54
FOREST	56682.	5.14	0.00	5.54	5.54	0.17	0.17
LOGGING	20.	0.00	47.13	0.00	0.18	0.00	0.08
BARN YARDS	41.	35.45	0.00	4.26	4.26	0.74	0.74
RES-imperv	104.	70.37	0.00	0.00	0.85	0.00	0.08
RES-perv	546.	8.69	0.00	0.00	0.28	0.00	0.04
COMM-imperv	49.	70.37	0.00	0.00	0.90	0.00	0.10
COMM-perv	41.	8.69	0.00	0.00	0.02	0.00	0.00
INDUS-imperv	34.	70.37	0.00	0.00	0.62	0.00	0.07
INDUS-perv	67.	8.69	0.00	0.00	0.03	0.00	0.01
GROUNDWATER				134.79	134.79	5.15	5.15
POINT SOURCE				45.60	45.60	9.90	9.90
SEPTIC SYSTEMS				38.10	38.10	1.11	1.11
TOTAL				340.89	387.61	28.08	47.45

W. Branch Delaware River 4/78-3/82 YEAR 4

	PRECIP	EVAPOTRANS	GR.WAT.FLOW	RUNOFF	STREAMFLOW
		(cm)			
APR	10.3	2.1	5.0	0.1	5.1
MAY	13.0	7.4	8.1	0.5	8.6
JUNE	8.1	10.4	1.4	0.0	1.4
JULY	7.0	11.4	0.1	0.0	0.1
AUG	5.4	8.7	0.0	0.0	0.0
SEPT	13.7	5.4	0.0	0.0	0.0
OCT	13.1	2.9	4.6	0.2	4.7
NOV	5.9	0.7	7.3	0.0	7.3
DEC	8.2	0.1	4.3	1.1	5.5
JAN	6.6	0.1	4.6	0.4	5.0
FEB	9.1	0.1	5.9	1.5	7.4
MAR	9.0	0.7	10.7	1.8	12.5
YEAR	109.4	50.0	52.0	5.7	57.7

	EROSION	SEDIMENT	DIS.NITR	TOT.NITR	DIS.PHOS	TOT.PHOS
	(1000 Mg)			(Mg)		
APR	28.0	0.0	23.5	23.9	1.6	1.7
MAY	55.8	0.4	39.3	40.8	2.3	2.9
JUNE	15.4	0.0	9.3	9.4	1.1	1.1
JULY	20.1	0.0	4.6	4.8	0.9	1.0
AUG	12.7	0.0	4.3	4.5	0.9	0.9
SEPT	43.2	0.0	4.6	4.9	1.0	1.0
OCT	10.5	0.2	23.0	23.8	1.6	1.9
NOV	2.4	0.0	29.5	29.7	1.7	1.7
DEC	0.5	3.6	32.0	43.2	2.2	7.0
JAN	0.0	0.7	30.6	32.9	2.6	3.5
FEB	0.0	4.3	51.9	65.1	4.5	10.1
MAR	0.7	3.1	82.0	91.6	6.7	10.7
YEAR	189.3	12.3	334.7	374.4	27.2	43.5

SOURCE	AREA (ha)	RUNOFF (cm)	EROSION (Mg/ha)	DIS.NITR	TOT.NITR	DIS.PHOS	TOT.PHOS
					(Mg)		
CORN	3430.	14.66	38.98	44.57	70.64	6.60	17.89
HAY	13085.	10.52	2.19	8.54	44.12	2.06	4.48
PASTURE	5093.	6.48	2.91	9.90	12.79	0.82	2.08
INACTIVE	3681.	6.48	3.10	3.81	6.04	0.31	1.27
FOREST	56682.	3.67	0.00	3.95	3.95	0.12	0.12
LOGGING	20.	0.00	39.52	0.00	0.15	0.00	0.07
BARN YARDS	41.	31.05	0.00	3.73	3.73	0.65	0.65
RES-imperv	104.	68.27	0.00	0.00	0.87	0.00	0.09
RES-perv	546.	6.96	0.00	0.00	0.30	0.00	0.04
COMM-imperv	49.	68.27	0.00	0.00	0.92	0.00	0.10
COMM-perv	41.	6.96	0.00	0.00	0.02	0.00	0.00
INDUS-imperv	34.	68.27	0.00	0.00	0.64	0.00	0.07
INDUS-perv	67.	6.96	0.00	0.00	0.04	0.00	0.01
GROUNDWATER				146.50	146.50	5.60	5.60
POINT SOURCE				45.60	45.60	9.90	9.90
SEPTIC SYSTEMS				38.10	38.10	1.11	1.11
TOTAL				334.70	374.40	27.18	43.49

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Attachment F

Comment And Response

COMMENT AND RESPONSE DOCUMENT
Donegal Creek TMDL

General:

Comment: It is unclear if there is authority under state law or regulation for promulgating TMDLs for nonpoint sources or pollution, as 25 PA Code §§ 95.3 and 95.9 clearly authorizes for point sources. Specifically under § 95.9, DEP is authorized only to limit point sources of phosphorus even if nonpoint sources are the predominant source of pollution. (1)

Response: The Department has authority under state law and regulation, including the Clean Streams Law and 25 Pa. Code Section 95.3(d), and federal law and regulation including Section 303(d) of the Clean Water Act and 40 CFR Section 130.7. The authority and legal basis for nonpoint source TMDLs was recently affirmed in the case of Pronsolino v. EPA, N.D. Cal., No. C99-1828 (3/30/00). Finally, Section 95.9 addresses point sources of phosphorus and does not limit the Department's ability to address nonpoint source pollution from phosphorous in any way.

Comment: We appreciate DEP efforts in translating the narrative water quality criteria into a quantitative TMDL and conceptually approve of the modeling technique used. We also recommend that DEP consider developing numeric criteria for phosphorus and sediment. (1)

Response: EPA is currently working with states to develop criteria for nutrients, which are projected for later this year. States will have three years to adopt the recommended criteria into their water quality standards.

Comment: Before listing Donegal Creek as not meeting a nutrient standard, DEP should consider the legal precedent requiring translation of the narrative nutrient criteria into numeric values. (3)

Response: The stream was listed as not attaining standards based on the biology survey. The surveyor's best professional judgement was used to determine the source and cause of the impairment. Nutrients were listed as one of the causes based on the excessive algal growth found in the stream.

Comment: Is Donegal Creek properly designated or should it be WWF, which may be more appropriate for stream through low, high quality agricultural land? (3)

Response: The designated use of a stream is based upon biological surveys that determine the water uses of the stream and not on the surrounding land use. Designated uses are adopted as regulations by the Environmental Quality Board upon recommendations made by the Department. As with other regulations, citizens may petition the Board to change the designated uses of streams.

Comment: The TMDL does not state if the Rapid Bioassessment Protocol described on page 4 was used for the biological surveys that determined the water quality impairment. This should be clarified. (2)

Response: As stated in the TMDL, Donegal Creek was listed in 1996 as the result of a biological assessment that included kick screen analysis and habitat assessments. The follow-up survey in 1997 did use the Rapid Bioassessment Procedure.

Listing Issues:

Comment: Listing documentation does not explain why Donegal Creek was made high priority for TMDL. (3)

Response: States may use judgement in prioritizing streams for TMDLs within two years of listing. Donegal Creek was made high priority for TMDL development because there were already significant BMPs being installed in the watershed and results of the remediation would be apparent in a shorter time from than other streams whose impairment was not being addressed. DEP was developing the new "reference watershed approach" to nonpoint source TMDLS and considered Donegal a good model on which to develop the procedure.

Reference Stream:

Comment: We recommend using a theoretical reference stream in modeling the TMDL. Loading capacity is the maximum concentration of a pollutant at which a stream can attain water quality standards. The TMDL should equal the loading capacity plus a quantitative margin of safety. The reference stream used in this TMDL development is not impaired and therefore, by definition, its pollutant concentrations are significantly lower than the loading capacity. A theoretical reference stream would account for a loading capacity at the exact threshold necessary to maintain water uses. (1)

Response: Establishing the parameters for a theoretical reference stream would be extremely difficult. There is also no actual measure of the instream biodiversity and abundance available for this approach. This is one reason why EPA is in the process of developing nutrient criteria. EPA supports the use of the reference watershed approach.

Comment: The reference watershed approach is to be commended. It offers an interesting promise in TMDL development in focusing on the watershed, land use and land use practices where it belongs. This is better than the eternal data collection and modeling simulation that stalemates water quality improvement. (2)

Response: Thank you for the supportive comment.

Comment: There is insufficient explanation as to why DEP believes the reference watershed meets water quality standards. The geology and topography could also have a significant effect on the water quality. (2)

Response: Brubaker Run meets water quality standards based on the assessment of the biology in the stream.

Comment: The TMDL does not specify how the reference watershed was determined to not be impaired for nutrients or sediment nor if the assessment method accounts for seasonal variability. A reference watershed must meet standards throughout the year. (2)

Response: The reference watershed was assessed using the RBP and determined to meet water quality standards. The RBP provides evaluation of the macroinvertebrate population of a stream, which is an indicator of long term attainment of uses.

Modeling Issues:

Comment: There is no rationale for selecting 10% as the margin of safety. (2)

Response: Ten percent of the TMDL load is based on professional judgement and will provide an additional level of protection to the uses of the waterbody. This statement is included in the TMDL.

Comment: Sensitivity analysis of the model factors should be done and instream data used for factors with highest degree of sensitivity. (3)

Response: There was no instream water chemistry data available to adjust the model variables in this manner. The model has been calibrated on a number of watershed that have water quality network stream monitoring stations on them. This was done to make adjustment to the model algorithms to give the best results using the values that are estimated through the model interface.

Comment: DEP should assess the degree of certainty for each factor in the modeling to determine if an additional 10% margin of safety is necessary to add in the TMDL. (3)

Response: The use of resources to assess the degree of certainty for all the model factors would be huge and would significantly delay the development of TMDLs. DEP's Best Professional Judgement is that10% is a fair margin of safety to use to make up for unknowns in the TMDL development process.

Comment: DEP should attempt to quantify the benefits of the TMDL and its cost so that agencies can assess their need to respond to the proposals. (3)

Response: Costs will be considered in the implemetation phase of this process.

Comment: The TMDL fails to establish a daily load as required by the Clean Water Act, and only offers a yearly load. Daily loadings and streamflows should be calculated for critical or frequent seasonal weather conditions. These could easily be extracted from the internal calculations of the AVGWLF model and would be more useful for monitoring loads and enforcing TMDLs. (2)

Response: The CWA requirement for total maximum daily loads allows for the expression of a TMDL in units of mass per time, toxicity, or other appropriate measures. DEP in consultation with EPA has determined that annual loadings are more appropriate for expression of nonpoint source TMDLs for nutrients and sediment.

Comment: Although DEP uses daily time steps for data to estimate a yearly load, it failed to use the data to calculate a daily load that assures standards are met in all seasons of the year, as required by the CWA. (2)

Response: See previous response.

Comment: The annual TMDL does not explain how it accounts for seasonal variations. Is water quality impaired all year or only during particular periods? (2)

Response: TMDLS for nonpoint sources of pollution are developed to protect the stream from impacts that occur at "critical" conditions. Critical conditions for nonpoint sources are times of runoff usually associated with precipitation. Similar to the way TMDLS protect waters from point source pollution at the critical low flow condition ensures protection at other less critical periods, TMDLs developed to protect the stream from impact of nonpoint sources during runoff ensure protection under all other conditions.

Comment: DEP concluded that phosphorus is always the limiting nutrient based on an annual ratio of 37:1. Since ground water is a major source of nitrogen, there would be a significant nitrogen source during the dry summer months. Phosphorus enters a stream mainly through overland flow in runoff, mostly during wet, winter months. This changes the N:P ratio seasonally and would require a TMDL for nitrogen for particular seasons. (2)

Response: Although ground water contributions of N will be highest relative to overland runoff contributions during the summer months (May through September), total nitrogen loads will normally be lowest in these months due to low flows and increased plant uptake. Therefore, seasonal implementation of BMPs to control these summer nitrogen loads would not be an effective means of improving the water quality in Donegal Creek as these are not the "critical" conditions assessed in Pennsylvania's nonpoint source TMDLs.

Phosphorus does enter the stream through overland flow in runoff; however, periods of high P exports correspond to periods of high soil loss. During the wet winter months, there is normally enough ground cover to dissipate the erosive energy of precipitation. Total P loads, on a unit area basis, are typically highest in the fall (after harvest when more bare soil is exposed) and in the spring (more intense rainfall events on fields being prepared for planting). However, TN loads are also higher in the fall and spring such that the N:P ratio remains greater than 10.

Comment: If a TMDL for nitrogen is needed because of seasonal variations, the riparian restoration will not adequately reduce nitrogen from groundwater sources. (2)

Response: See previous response regarding the need for a nitrogen TMDL.

Comment: DEP has made a reasonable allocation of the loads of the pollutants, phosphorus and sediment, among the nonpoint sources in the watershed, but we question if those are the only pollutants requiring TMDLs, as discussed above. (2)

Response: Thank you for the supportive comment on the allocation procedure. See previous two comments regarding the need for a TMDL for nitrogen.

Comment: DEP inadequately accounts for the differences (topography, stream density, geology, annual water yield, animal densities, crops and cropping practices) other than watershed size between Donegal Creek and the reference watershed. DEP should make a better attempt to account for the differences.

Response: DEP disagrees with the statement that the modeling analysis does not adequately account for differences in many of the factors listed. Topography and stream density are used in the GIS data derived generation of the Universal Soil Loss Equation (USLE) parameters assigned to model soil erosion. Differences in these factors are realized in the LS factor in the USLE for each watershed. Differences in animal density are accounted for in the model using a GIS coverage of animal populations by zip code as obtained from the U.S. Census of Agriculture. This data layer is used in determining the amount, and nutrient content, of manure applied to cropland in each watershed. Differences in crops and cropping practices are also accounted for both through GIS generation and manual manipulation of the C and P factors in the USLE. Using GIS coverages with typical county-based cropping and BMP implementation practices, C and P factors are generated for each watershed. These factors were further adjusted for Donegal Creek and Brubaker Run based on specific information gleaned through discussions with district conservationists working in these watersheds. The adjustments made to the GIS generated C and P values are documented in the Watershed Assessment and Modeling section of the TMDL document under *Adjustments to specific GWLF-related parameters*. Finally, geologic similarity is used as one of the criteria for choosing a reference watershed. Also, model parameters such as the groundwater recession coefficient are adjusted based on the underlying geology in the watershed. Therefore, differences in groundwater contributions due to dissimilar geology are accounted for in the analysis.

Comment: DEP should look at other factors, not limited to the fate and transport processes that occur as as sediment and nutrients move downstream. (2)

Response: GWLF does not have an in-stream module with which to model the fate (e.g. biological utilization, sequestration in bed sediments) and transformation of nutrients. The model currently uses widely accepted, literature-based delivery ratios to obtain a delivered load from an edge-of-stream load. A process based in-stream module would require the estimation of many state- and rate- variables for which very little, if any, data exist. DEP is exploring the possibility of incorporating a more empirical in-stream module into the AVGWLF framework.

Comment: DEP should normalize watershed loadings by watershed streamflows, that is the loading rate objective for Donegal should be the areal loading rate for the reference multiplied by the ratio of Donegal to reference streamflow yields. (2)

Response: Loading rates discussed in the TMDL are delivered loading rates, not edge-of-stream loading rates. Nutrient loads are calculated based on a modeled constituent concentration in streamflow and streamflow volume; therefore, further normalizing the nutrient loading rates by streamflow would effectively double-count the effects of streamflow on nutrient export.

Follow-up Monitoring:

Comment: DEP or others should quantify the improvement in DO, nitrogen, phosphorus and aquatic life resulting from the BMPs. The data would, among other things, refine modeling efforts. (3)

Response: Although not part of the TMDL, but rather, of the next step in the process – implementation – follow-up monitoring will be used to measure the success of implementing the TMDL. Determining if a stream meets water quality standards will be based primarily on the same criteria that put it on the list originally. In this case, it would be a biological assessment. Nevertheless, the Department supports the collection of chemical data as resources permits.

Implementation, BMPs:

Comment: Implementation of the BMPs in the TMDL is obvious and will stabilize the riparian zone. No TMDL is necessary to justify the implementation of the BMPs already being carried out. (3)

Response: DEP acknowledges that the implementation of BMPs in the Donegal Watershed preceded the development of the TMDL. The TMDL is necessary under 40 CFR Part 130.7 of the federal regulations, which requires TMDLs be developed for all waters listed on the 303(d) list of impaired waters.

Comment: The proposed implementation plan appears reasonable for phosphorus. However, the document states sediment reduction will be met only if BMPs are applied to the whole watershed and it is not specified if BMP implementation is planned for the whole watershed. It is also apparently assumed that all landowners on impaired segments will participate, and no reasonable basis for that assumption is given. (2)

Response: Implementation of the streambank fencing in impaired areas has already occurred. Some further reduction in sediment loading is needed; however, this does not require participation of all landowners in the watershed.

Comment: There is no connection between using the AVGWLF model to develop loading objectives and the selection of practices for implementation from a set of limited and primitive estimates. The model should be a powerful tool for selection of BMPs and should be used for that purpose. (2)

Response: The model does not allow for the direct input of BMPs on the landscape to predict reduction values. GWLF is a lumped parameter model; therefore, assessment of reductions due to BMP implementation in impaired subwatersheds must be done external to the model.

Comment: The generalized reduction coefficients from BMPs do not seem appropriate. The model should be considered more reliable than the generalized values cited as implementation assurance for this TMDL. (2)

Response: The model was used to predict the current loading value for the watershed. Parameter adjustments to account for BMPs would have to be made without a clear method for determining the new values. Therefore, scientifically derived or measured reductions, such as those used in this TMDL as published by the US EPA Chesapeake Bay Program, are felt to be more defensible.

LIST OF COMMENTATORS

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00 JAN 19 PM 1:45

January 18, 2000

Mr. Lee A. McDonnell
Bureau of Watershed Conservation
Department of Environmental Protection
10th Floor – Rachael Carson State Office Building
Harrisburg, PA 17105

Dear Mr. McDonnell:

Thank you for the opportunity to provide comment on the proposed Total Maximum Daily Load (TMDL) for Donegal Creek (Lancaster County). The Pennsylvania Builders Association has reviewed the proposal. We are primarily concerned with the process of TMDL establishment for non-point sources rather than the Donegal Creek TMDL in particular. Please consider the following comments.

1. It is unclear that authority exists under state law or regulation for the Department of Environmental Protection to promulgate TMDLs for non-point source pollutants. 25 Pa Code §95.3 and §95.9 clearly authorize the Department to do so for point source pollutants. However, the specificity of these regulations to point sources raises questions as to why, if regulation of non-point sources is authorized, similar sections covering them are not provided for in Title 25. Specifically under §95.9, when phosphorus contributes the impairment of a stream, as in Donegal Creek, the Department is authorized only to limit point sources even though non-point source loadings may be the predominant source of the pollutant.

2. The PBA appreciates the efforts of the Department in translating narrative water quality criteria into a quantitative TMDL. Further, PBA conceptually approves of the modeling techniques used to develop the TMDL. PBA further recommends that the Department consider developing numeric water quality criteria for phosphorus and sediment.

3. PBA is concerned about the use of reference watersheds to establish TMDLs. Loading Capacity represents the maximum concentration of a pollutant at which a stream can remain in attainment of water quality standards. A TMDL should equal Loading Capacity plus a quantitative margin of safety. In establishing the TMDL for Donegal Creek, DEP fails to establish the Creek's Loading Capacity. Because the designated water use of Brubaker Run, the reference stream, is not close to non-attainment, sediment and phosphorus concentrations in Brubaker Run are, by definition, significantly lower than its Loading Capacity. By using Brubaker Run as the standard for Donegal Creek, an artificially low Loading Capacity and an unquantifiable safety margin is established. PBA recommends using a theoretical reference stream in modeling TMDLs. This idealized reference stream would have Loading Capacity set at the exact threshold necessary to maintain designated water uses.

Sincerely,

Mark Maurer

Mark Maurer
Regulatory Specialist

cc: Senator Mary Jo White
Senator Raphael J. Musto
Representative Arthur D. Hershey
Representative Camille George
Mr. Robert Nyce

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January 18, 2000

Via Fax and Regular Mail

Lee A. McDonnell
Division of Water Quality Assessment and Standards
Bureau of Watershed Conservation
PA DEP
400 Market Street
Harrisburg, PA 17105-8555

Dear Mr. McDonnell:

The following comments on the proposed Total Maximum Daily Load ("TMDL") for phosphorus and sediment in the Donegal Creek watershed, Lancaster County, Pennsylvania are submitted by the Eastern Environmental Law Center on behalf of the Delaware Riverkeeper Network and their associate field-office, the Schuylkill Riverkeeper. These comments supplement (but do not supplant) any other comments submitted by this organization.

COMMENTORS

The Commentors comprise a nonprofit organization interested in ensuring that the quality of Pennsylvania waters is restored and maintained. As representatives of local and regional interests, the Commentors reflect a broad range of concerns for the health of Pennsylvania waters. The commenting organization has members who use and enjoy the waters in Pennsylvania and who are adversely affected by the pollution of these waters. Specifically, the Commentors' interest lies in ensuring that any TMDLs established, in any waters of Pennsylvania, set the right precedent for moving the establishment of future TMDLs in the right direction, which is, the attainment of water quality standards throughout Pennsylvania.

The Delaware Riverkeeper Network, established in 1988, and it's associate field office, Schuylkill Riverkeeper, established in 1996, have been working since their respective inceptions, to protect and restore the Delaware River, its tributaries and its habitats. Together, we work throughout the entire Delaware River Watershed, which includes portions of New York, New Jersey, Pennsylvania, and Delaware. Riverkeeper, including its field office, has over 6,000 members throughout the Delaware Watershed.

BACKGROUND

The TMDL program of Clean Water Act ("CWA") section 303(d) sets forth a clear process that all states must follow when compliance with standards has not been achieved for all waters. In short, each state must (1) identify all of its impaired waters, the current effluent limitations for which are "not stringent enough to implement water quality standards" and (2) for each identified water, establish daily pollutant load limits - TMDLs - of each pollutant contributing to the impairment. 33 U.S.C. §1313(d). TMDLs are to be calculated at a level that will ensure attainment of water quality standards and are to be implemented by allocating the loads among the water's point and nonpoint sources of pollution. Id.; 40 C.F.R. §§130.2(g), (h), (i), 130.7.

COMMENTS

The commentors provide the following comments based on their review of the proposed TMDL for phosphorus and sediment in the Donegal Creek watershed, Lancaster County, Pennsylvania. The comments focus on the following areas: (1) reference watershed approach; (2) reference watershed application; (3) failure to establish a daily load; (4) failure to account for seasonal variations; (5) identification of pollutants requiring a TMDL; (6) calculation of TMDLs; (7) allocation of TMDLs among non-point sources; (8) implementation plans; and (9) margin of error.

Reference Watershed Approach

The "reference watershed approach" the Department used to develop this proposed TMDL is an interesting idea. Coupling the GWLF model (or any comparable watershed loading model) with GIS data files as a basis for TMDL development is a significant step in the right direction. This approach focuses the TMDL development on the watershed and land use and land management practices (pollutant source controls), where it belongs, instead of on hypothetical instream chemical and biological processes that are the focus of a water quality simulation approach. A few concerns and suggestions about how the Department's approach is applied in the Donegal Creek watershed are detailed in the comments below. With the corrections suggested below, DEP's reference watershed approach and application of its AVGWLF model offer interesting promise for TMDL development and water quality management in Pennsylvania. Pennsylvania's focus on the watershed and land management practices, and away from the eternal water quality data collection and water quality simulation modeling that stalemates water quality improvement in many other states, is to be commended.

Reference Watershed Application

Generally, the reference watershed selected is appropriate. However, the draft document offers only minimal explanation as to why the Department believes the reference watershed meets water quality standards while the Donegal Creek watershed does not. The implication is that fewer livestock and the implementation of BMPs in the Brubaker watershed accounts for the difference. The commentors questions whether this explanation is adequate, when the differences in geology and topography between Brubaker Creek and Donegal Creek watersheds could also have a significant effect on the water quality.

Failure to Establish a Daily Load

The proposed TMDL fails to establish a total maximum *daily* load. It establishes only a yearly limit. This blatantly contravenes the Clean Water Act.

PADEP has not offered a valid explanation for failing to comply with the CWA's requirement to establish daily loads. However, assuming, *arguendo*, that the agency could explain away this failure, the department's attempted explanation is inadequate. The explanation provided for establishing a *yearly* maximum load is that there is "generally a significant lag time between the introduction of sediment and nutrients to a waterbody and the resulting impact on beneficial uses, [so] establishing these TMDLs using average annual conditions is protective of the waterbody." (p. 17.) No further explanation is provided for what the "lag time" is or why this makes a daily limit impossible. The department has not explained why setting a yearly limit, which presumably allows for daily, weekly, or monthly fluctuations in loads as long as the yearly total is not exceeded, adequately protects water quality on a *daily* basis. As noted previously, the Clean Water Act specifically requires that a total maximum *daily* load be established for impaired waterways. Congress clearly intended that water quality standards be met *every day*, not just most days or on an annual basis.

In addition to failing to meet statutory requirements, setting only annual loads is inadequate for performance monitoring and regulation enforcement. For these purposes, daily loadings and streamflows should be calculated for one or several critical or frequently encountered seasonal weather conditions. Such daily loading and streamflow values could be easily extracted from mass and water balance calculations already performed internally by AVGWLF. They would be more readily useful measures for monitoring of loads and enforcement of the TMDLs.

Failure to Account for Seasonal Variations

The department fails to explain how an annual TMDL meets the Clean Water Act requirement for establishing a maximum daily load for impaired waters that reflects seasonal variations.

First, the draft TMDL fails to specify whether water quality is impaired all year, or whether water quality is only impaired during particular time periods. While the document specifies that an aquatic biological survey was conducted to determine whether the Donegal Creek is impaired, it does not indicate whether this assessment method accounts for seasonal variations in water quality. In addition, the draft TMDL indicates that the reference watershed, Brubaker Creek, is not impaired for nutrients or sediment, but does not specify what testing was done to reach this conclusion and whether this testing accounted for seasonal variations. To be an appropriate reference watershed, Brubaker Creek must meet water quality standards throughout the year.

Second, the department asserts that the yearly TMDL accounts for seasonal variations because the model uses daily time steps for weather data and water balance calculations, and considers growing seasons, hours of daylight, and the months when manure is applied to the land. While the department appropriately used this seasonal data to estimate the total *yearly* loads in the subject and reference watersheds, the department failed to use the data to calculate a *daily* TMDL that assures water quality standards are met in all seasons of the year. The CWA requires the TMDL to be established "at a level necessary to implement the applicable water quality standards *with seasonal variations.*"33 U.S.C. §1313(d)(C). If water quality impairment varies due to seasonal differences in weather and agricultural activity, then TMDLs should be established for each relevant season or time period.

A specific example where failure to account for seasonal variations has affected the TMDLs established for Donegal Creek is in the conclusion that phosphorus is always the rate-limiting nutrient. The N:P ratio of 37:1 appears to be calculated from the ratio of total yearly nitrogen load to total yearly phosphorus load. However, the ratio of nitrogen to phosphorus must vary with seasonal conditions, because the major sources of each of these nutrients (per Table 5 and Table 6) contribute nutrients to the creek under very different conditions. According to the tables, the major source of nitrogen is groundwater, which presumably contributes significantly to total stream flow during dry summer months as the stream baseflow. During high flow periods, water from the stream would be expected to recharge the groundwater, so relatively little nitrogen would be entering the stream from groundwater during these periods. In contrast, the vast majority of phosphorus enters the stream overland through runoff, which presumably occurs mostly during wet winter months. Because relatively little nitrogen enters the stream during high flow periods while large amounts of phosphorus enter the stream, the ratio of N:P would therefore be expected to be much lower than 37:1 during high flow periods. If N:P becomes less than 10:1, then P can no longer be assumed to be the rate-limiting nutrient. The Department has decided a TMDL for nitrogen is not required because the annual ratio of N:P is 37:1; however, it fails to evaluate whether the ratio of N:P varies seasonally, thereby requiring that a TMDL for nitrogen be established for particular seasons.

Identification of Pollutants Requiring TMDLs

The Department has decided a TMDL for nitrogen is not required because the *annual* ratio of N:P is 37:1, indicating phosphorus is the rate-limiting nutrient in algae growth. The conclusion is inappropriate, as it fails to account for any seasonal variation in the ratio of N:P. If the ratio seasonally drops below 10:1, then phosphorus can no longer be assumed to be the rate-limiting nutrient, and a TMDL for nitrogen is required if the water quality is impaired during that season.

Calculation of TMDLs

In calculating the TMDLs for Donegal Creek, the Department inadequately accounts for the differences between the reference watershed and the Donegal Creek Watershed. The Donegal Creek TMDLs are calculated simply by scaling up the areal loading rates calculated for the Brubaker Creek Watershed based on the relative difference in watershed size (area) between

Donegal Creek and Brubaker Creek watersheds (Table 8). Although the two watersheds are similar in many ways, there are other differences besides watershed size (for example, topographic relief, stream density (stream miles/mi^2), geology, annual water yield, animal densities, crops, and cropping practices (see pp. 11-14 and Attachments A and B)). These differences influence the pollutant loads that can be accommodated by the streams. DEP's TMDL calculations should make a better attempt to account for these additional differences.

An analytical expression for an allowable loading would have the general form:

$$L_a/A = (Q/A)*C*(1 + k*t_r)$$

Where: L_a/A = areal loading rate
Q/A = areal streamflow yield
C = water quality criterion (concentration)
k = assimilation rate
t_r = mean travel time from source

The form of this expression provides some insight to the kinds of corrections that might be usefully added to DEP's present TMDL calculation. For example, topographic relief and stream densities will influence stream travel times and physical assimilation rates, that is, sedimentation. For some constituents, such as nutrients, the concentration criteria may also be influenced by these factors, for example, higher flow velocities may allow higher acceptable concentrations.

Certainly, relative streamflow yields need to be part of the TMDL calculation. The areal streamflow yield from the Brubaker watershed is 14.5% greater than from Donegal (Attachment A), so water quality in Brubaker Creek should tolerate a greater areal pollutant loading than would Donegal Creek. The distributions of streamflow sources between the two watersheds should also be part of the TMDL calculation. The surface runoff portion of the Donegal Creek streamflow is 29% greater than the surface runoff portion of Brubaker Creek's streamflow, and sediment loadings, and probably most of the phosphorus, are associated more with surface runoff than with the groundwater inflows. It follows therefore that surface source controls and land management practices are more critical for the Donegal Creek watershed than for Brubaker Creek and have a greater effect on the resulting water quality.

Accounting for these and other watershed differences within DEP's reference watershed approach should not be difficult. For example, many of the geomorphological differences between the Donegal and Brubaker watersheds will be reflected in their different streamflow yields. It would make sense therefore to at least normalize watershed loadings by watershed streamflows, that is, a better areal loading rate objective for Donegal Creek would be the areal loading rate for Brubaker's watershed multiplied by the ratio of Donegal to Brubaker streamflow yields.

Allocation of TMDLs Among Non-Point Sources

Assuming that phosphorus and sediment are the only pollutants requiring TMDLs to protect water quality in Donegal Creek (and we question that assumption, as explained in "Identification of

Pollutants Requiring TMDLs" above), the department has made a reasonable allocation of the loads among non-point sources in the watershed.

Implementation Plans

If the expected reduction in pollution due to BMPs cited in the draft document are accepted as reasonable (see comments below questioning this assumption), the proposed implementation plan appears to provide reasonable assurance that the required load reductions for phosphorus (50%) can be achieved. However, according to the estimates provided, sediment loads will not be reduced by 61% unless BMPs are introduced watershed-wide, not just on the impaired segments of the stream. The document does not specify if BMP implementation is planned for the whole watershed or just for impaired areas. Also, the draft document fails to consider the expected BMP compliance rate for landowners. The numbers used apparently assume 100% participation on the impaired segments of the stream. No reasonable basis for this assumption is provided.

The commentors also question the apparent disconnect between the Department's effort and use of the AVGWLF model to develop watershed loading objectives and then, according to the description of BMPs under "Reasonable Assurance of Implementation," its selection of the practices for implementing these loading objectives (streambank stabilization and fencing) from a very limited and primitive set of estimates (Table 5 in Attachment C) with no evident consideration of the AVGWLF model.[1] The AVGWLF model for Donegal Creek watershed should be a powerful tool for selection of management practices to achieve the watershed loading objectives. Various reduced combinations of values for AVGWLF's crop management factor (C) and conservation practices factor (P) could be used in the model to simulate the watershed loading objectives for Donegal Creek. For each acceptable combination of C-factor and P-factor values, there will be an associated array of site-specific crop management and conservation practices. These practices are tabulated for different crops, pasture, and woodland in the GWLF Users Manual (Tables B-11, B-12, B-13, in the version 2.0 Users Manual). Thus, AVGWLF could generate a sophisticated array of acceptable, location-specific management practices from which land owners/managers could select. It is a mystery why the DEP does not use this model, already laboriously developed and in hand, for this purpose.

Absent more careful study of the references cited (Qui and Prato, 1998; Illinois EPA, 1986; SRBC, 1996), the generalized reduction coefficients listed for BMPs for the Donegal Creek remediation plan and in Table 5 in Attachment C do not seem appropriate. The 75% reduction listed for streambank stabilization and fencing may be reasonable for streambank and riparian area erosion, but seems large for application to sources throughout the watershed. Conversely, the small reductions listed for farming practices in Attachment C do not correspond to potential reductions indicated by available variances in C-factor and P-factor values in the GWLF model. In any event, as noted above, the GWLF model assessments of site-specific and crop-specific management practices should be considered far more reliable than the generalized coefficients cited as

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[1] AVGWLF is used by DEP to calculate the existing loadings for Donegal Creek, but only to estimate the fractional overall reductions needed to achieve the Brubaker areal loading rates. Practices that match these fractional loading reductions are then selected from literature estimates or the brief list in the TMDL's Attachment C, Table 5.

implementation assurance for this TMDL.

The commentors also note that if a TMDL for nitrogen needs to be established to account for seasonal variations in pollutant loadings, the riparian restoration plans relied upon in this implementation plan will be inadequate to reduce nitrogen loads from groundwater sources, which is the major source of nitrogen pollution in Donegal Creek.

<u>Biological Assessment</u>

The draft TMDL document states that aquatic biological surveys were conducted in 1994 and 1997 to determine water quality impairment, but it does not specify whether the Rapid Assessment Protocol described on page 4 was the method used. This point needs to be clarified.

<u>Margin of Safety</u>

The department fails to provide a rationale for selecting 10% as the margin of safety.

The commentors appreciates the opportunity to provide these comments for your review. Please contact me if you should have any questions regarding this submission.

Very truly yours,

James M. Stuhltrager

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PROPOSED TMDL
FOR DONEGAL CREEK WATERSHED

PENNSYLVANIA DEPARTMENT OF ENVIRONMENTAL PROTECTION

PUBLIC MEETING

December 9, 1999
Marietta, Pennsylvania

Submitted by
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OUR EXPERIENCE

Mr. Thunder's Experience

Mr. Thunder has 15 years' experience in environmental law, management, policy, and education. He has served as enforcement counsel with U.S. EPA, as instructor of environmental law at DePaul University College of Law, counsel to the Chemical Manufacturers Association, in private practice with Squire, Sanders & Dempsey representing industry and municipalities, and as corporate environmental manager with world-wide responsibilities for Johnson Controls, Inc., Milwaukee. He has been widely published on reforming regulatory government to better protect the environment while facilitating business and, in this regard, tracks the work of the Pennsylvania Department of Environmental Protection. He has worked in the areas of facility permitting, chemical usage, wastewater, drinking water, groundwater, pesticides, hazardous and solid wastes, the introduction of nonindigenous species, and more.

He has handled a number of Clean Water Act matters involving industry and publicly owned treatment works (POTWs). He became involved in 303(d) issues as a member of a team representing several POTWs in the Upstate area of South Carolina. The judge rendered his opinion in *Western Carolina Regional Sewer Authority v. S.C. Dep't of Health & Envtl Control*, Dkt Nos. 98-ALJ-07-0267-CC and -0585-CC, 1999 SC ENV LEXIS ___, on September 22, 1999. This was the first case in the country where a court ordered *removal* of a waterbody from a 303(d) list. The court took this action in the face of the South Carolina agency's arguments that the POTWs had no standing to contest a mere list, that their claims were not ripe because no formal TMDL had been developed, and that EPA's approval of the list preempted state administrative or judicial action. Furthermore, Mr. Thunder has addressed the Clean Water Industry Coalition on 303(d) issues.

Mr. Dole's Experience

Steve Dole has more than 20 years of experience as a natural resource manager for Fortune 500 companies and has spent the last three years as a consultant for Exponent. His background includes environmental permitting for industrial development, management of major Superfund sites, and environmental litigation both in support roles and as an expert witness. Focusing on natural resource regulations, Mr. Dole has commented extensively on TMDL developments in various states, including Georgia, California, and Colorado, and has developed strategies for companies that are grappling with TMDL issues.

Best Management Practices (BMPs) for Donegal Creek

- The need for implementation of the BMPs recommended by PaDEP -- fencing and restoration of riparian vegetation -- is obvious. It will stabilize the riparian zone of Donegal Creek.

- No TMDL is necessary to justify the implementation of these BMPs. (Indeed, some work is already being implemented.)

- If no TMDL were established, it may still be useful to PaDEP, the landowners, and others to quantify the improvement caused by the implementation of these BMPs by measuring dissolved oxygen (D.O.), nitrogen, phosphorus, and aquatic life before and after the BMPs are implemented. Among other things, these data may be used to support and refine modeling efforts.

Placement of Donegal Creek on the 1998 303(d) List of Impaired Waters

- Listing under Section 303(d) of the Clean Water Act has mandatory, regulatory effects, such as the establishment of a TMDL which, in turn, affects point sources, if any, and nonpoint sources. These regulatory requirements place burdens on PaDEP (for example, to develop, implement, and report on a TMDL).

- The listing of a stream segment on the 303(d) list assumes that the designated uses for the water are correct and the water fails to meet the applicable water quality criteria.

    - <u>Designation</u>: Should Donegal Creek have the same designated use as a mountain stream like Brubaker Creek, which was chosen by PaDEP as the reference stream? Or should it be required to meet the lesser standards assigned to a warmwater fishery -- arguably more appropriate for a stream running through low, high-quality agricultural land?

    - <u>Definition of Applicable Water Quality Criteria</u>: Whether Donegal Creek is designated as a coldwater or warmwater fishery, PaDEP should consider legal precedent requiring that PaDEP translate narrative criteria for nutrients into numeric criteria for nutrients giving a numerical, objective value to its target for water quality <u>before</u> it can lawfully say that Donegal Creek fails to meet that value and should therefore be listed. 57 Fed. Reg. 33040, preamble at III.B.2.b.v. third paragraph (July 24, 1992) (discussion of amendments to 40 CFR 130.7 (b)(3) regarding interpreting narrative criteria to establish the "applicable standard" for making Section 303(d) listing determinations), cited by *Western Carolina Regional Sewer Authority v. S.C. Dep't of Health & Envtl Control*, Dkt Nos. 98-ALJ-07-0267-CC and -0585-CC, 1999 SC ENV LEXIS ___ (Sept. 22, 1999), at para. 54.

Scheduling the Development of a TMDL for Donegal Creek Before 2000

- For waters listed under 303(d), PaDEP is required by 303(d) to "establish a priority ranking for such waters, taking into account the severity of the pollution and the uses to be made of such waters."

- The documentation for the proposed TMDL does not state why Donegal Creek was listed as a "high" priority water earmarked for the development of a TMDL before the year 2000 and is, therefore, one of the earliest TMDLs to be developed in the state.

The Proposed TMDL

- Sensitivity Analysis: The factors in the model should be analyzed for their sensitivity (that is, the degree to which the change in the numerical value assigned to a particular factor will alter the outcome). For the factors with the highest degree of sensitivity, actual in-stream data should be used.

- Margin of Safety: Each factor in the model is based on assumptions and each assumption has a degree of certainty. With each factor, PaDEP cumulates conservative assumptions rendering an overall margin of safety. If this margin of safety, intrinsic to all modeling, is sufficient, there is no need for PaDEP to add a 10% margin, extrinsic to its model, at the end of its analysis. To assess whether the intrinsic margin of safety is sufficient, PaDEP should assess the degree of certainty for each factor. If not, the proposed TMDL will have the effect of overcommitting resources to meet unachievable goals.

- Costs/Benefit: Whether or not required by any state or federal law or regulation, PaDEP will better serve the citizens of Pennsylvania by attempting to quantify the benefits of a proposed TMDL and its costs. Citizens need to know the effect of proposals made by state agencies in order to assess their need to respond to the proposals. For example, the documents refer to the receipt and earmarking of $100,000 in Section 319 funds to pay for BMPs, but the documents do not state how these monies will be allocated among the landowners abutting Donegal Creek, or whether these monies will be sufficient or, if not sufficient, how much more money will be needed.