APPENDIX A. GWLF User's Manual

G W L F

GENERALIZED WATERSHED LOADING FUNCTIONS

VERSION 2.0

USER'S MANUAL

December 15, 1992

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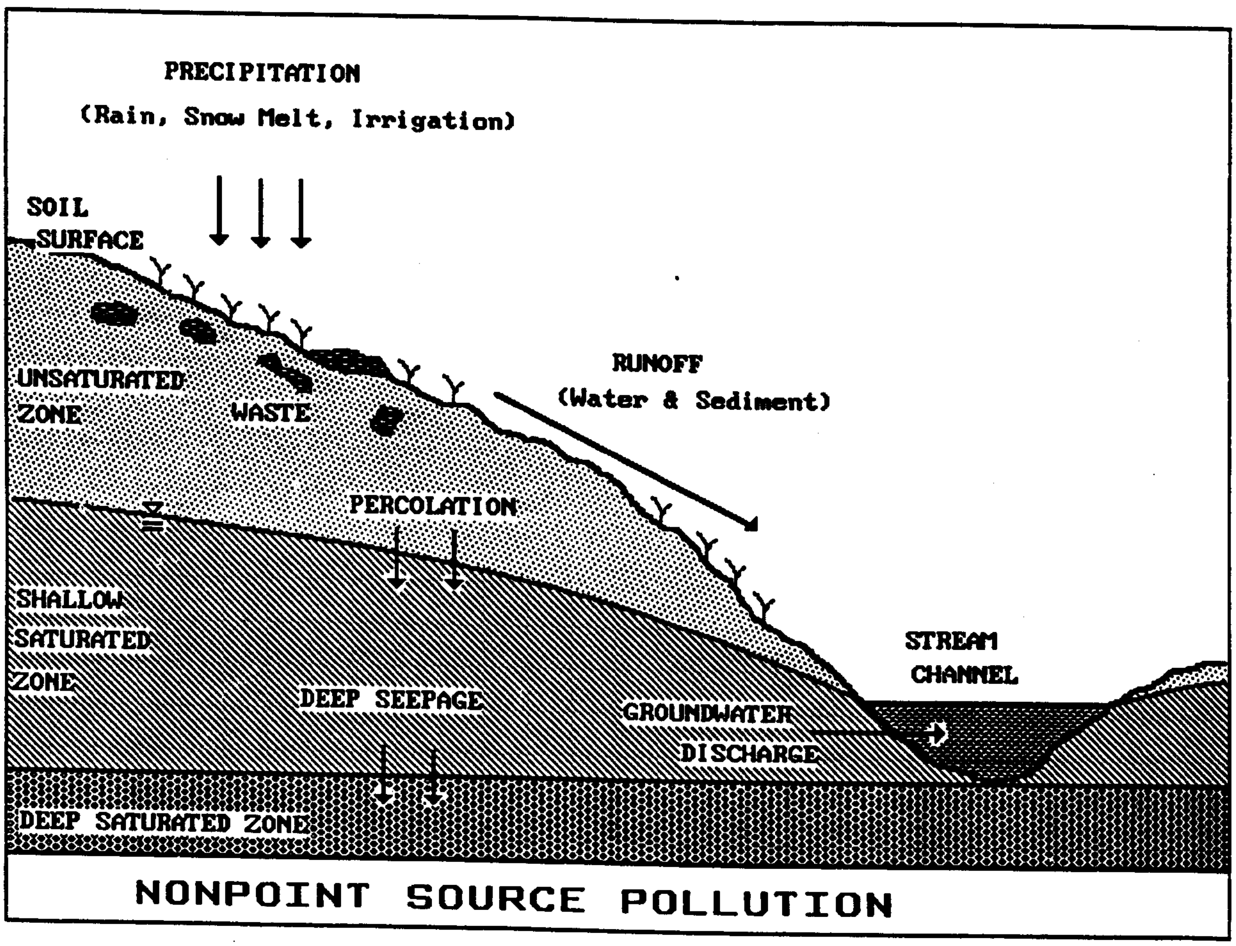

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INTRODUCTION

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 without 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.

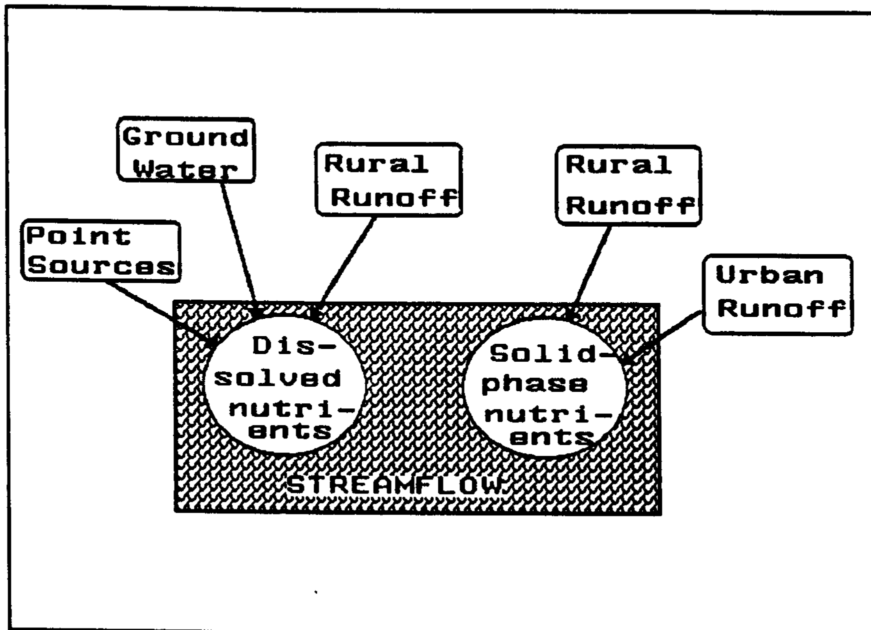

Figure 1. Nutrient Sources in GWLF.

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

```
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.

leads to the modification mode. After input/modification, the user can obtain a hard copy of the transport data by selecting Print TRANSPORT data.

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.

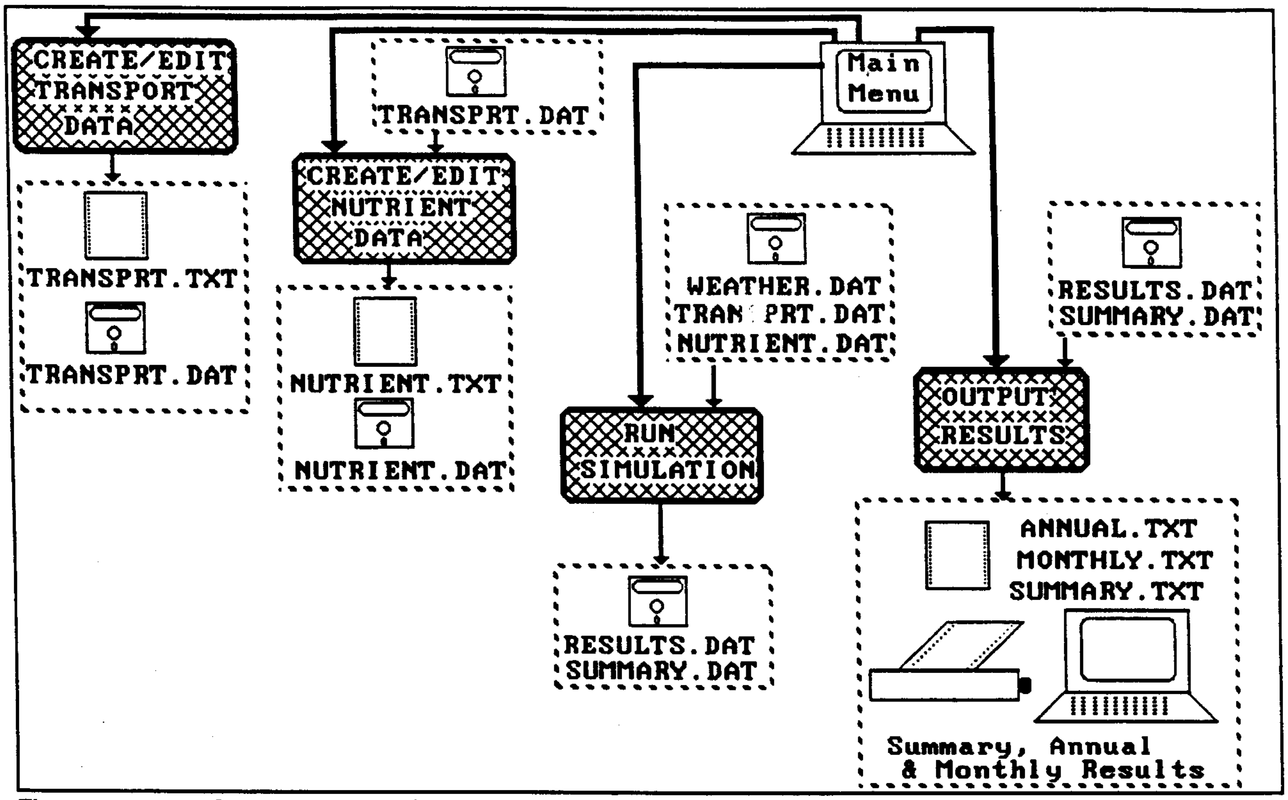

Figure 2. Structure of the GWLF Program.

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.,

```
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.

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.

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

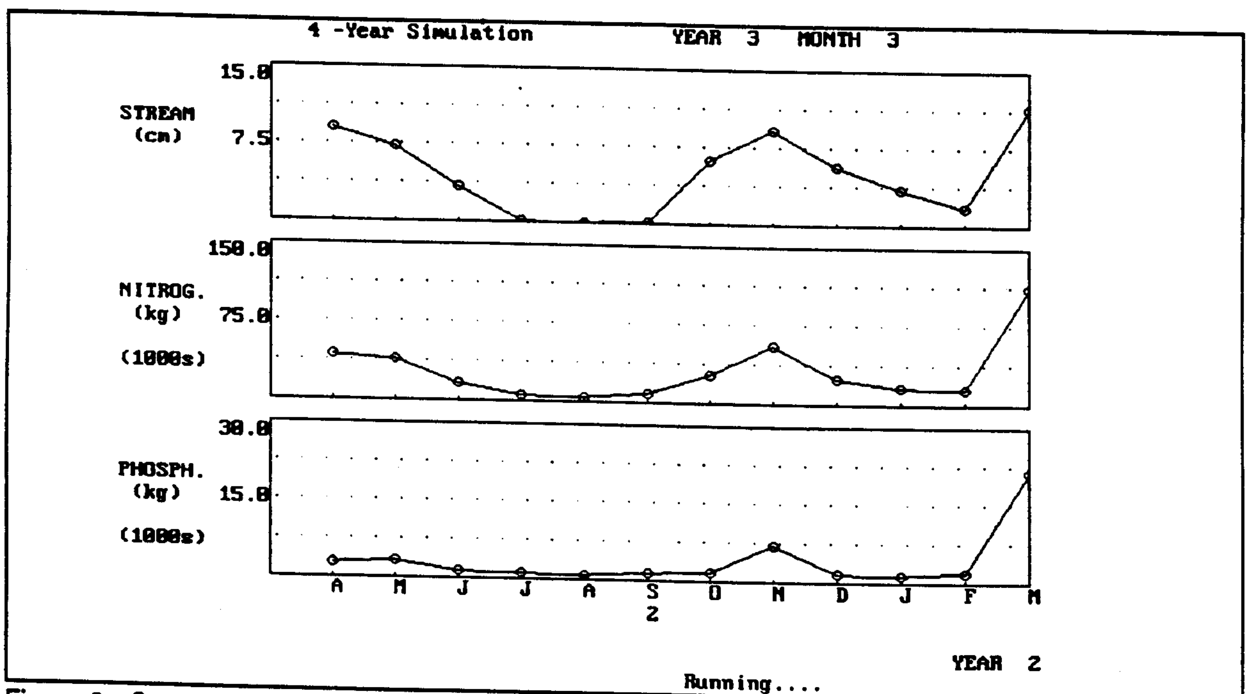

Figure 3. Screen Display during Simulation.

month/year.

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*.

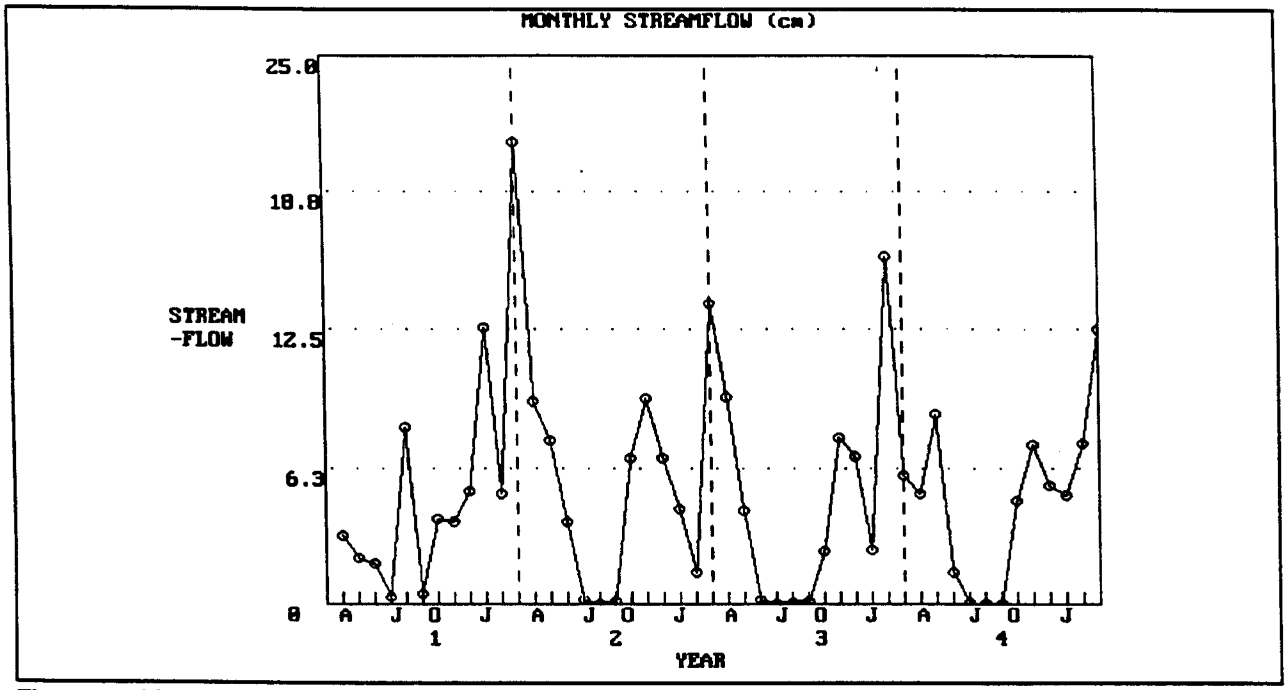

Figure 4. Monthly Streamflows for Example 1.

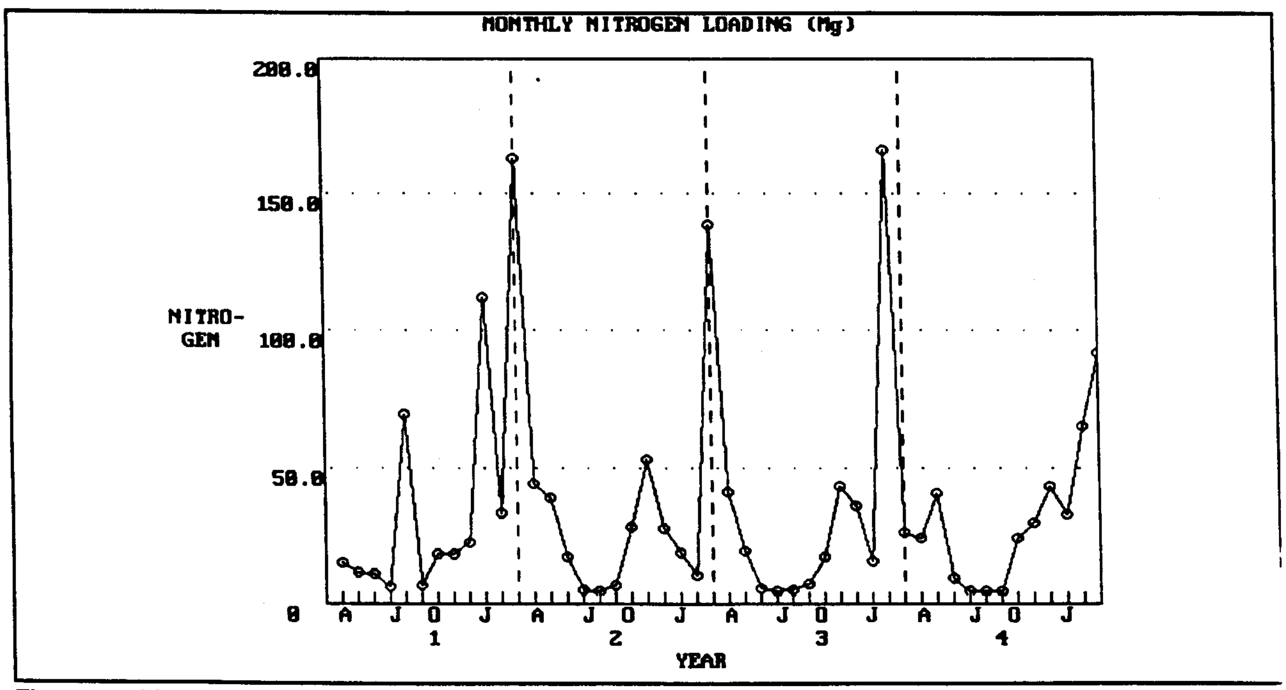

Figure 5. Monthly Nitrogen Loads for Example 1.

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.

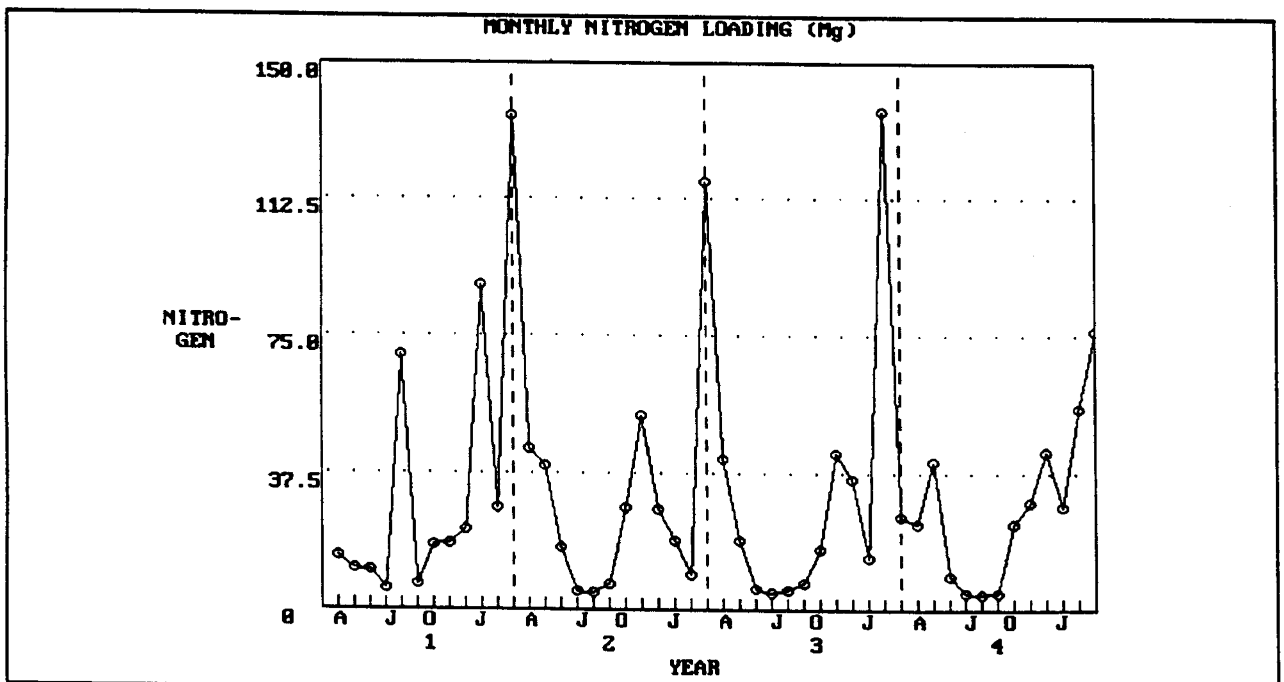

Figure 6. Monthly Nitrogen Loads with no Manure Spreading.

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

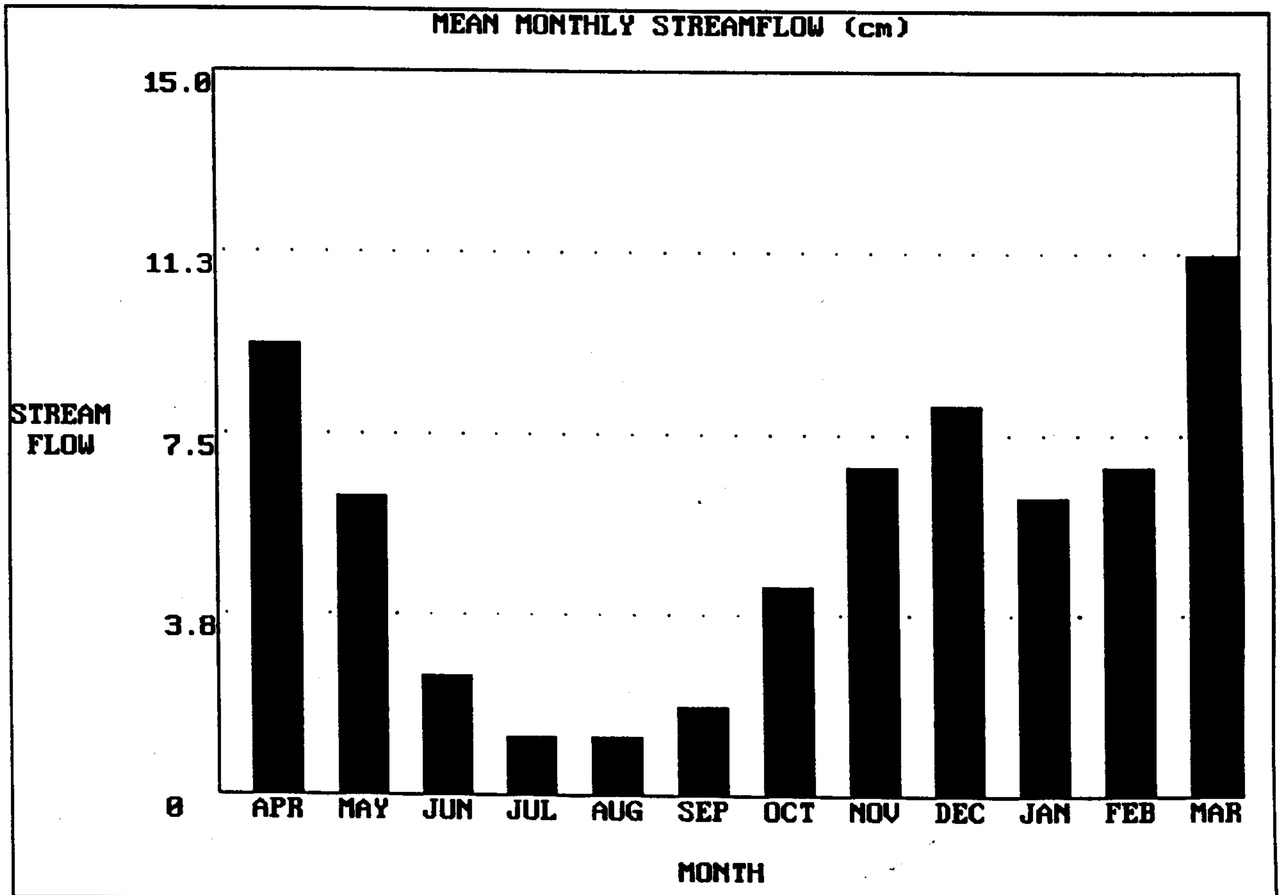

Figure 7. Mean Monthly Streamflows for 30-yr Simulation.

machine with math co-processor.

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

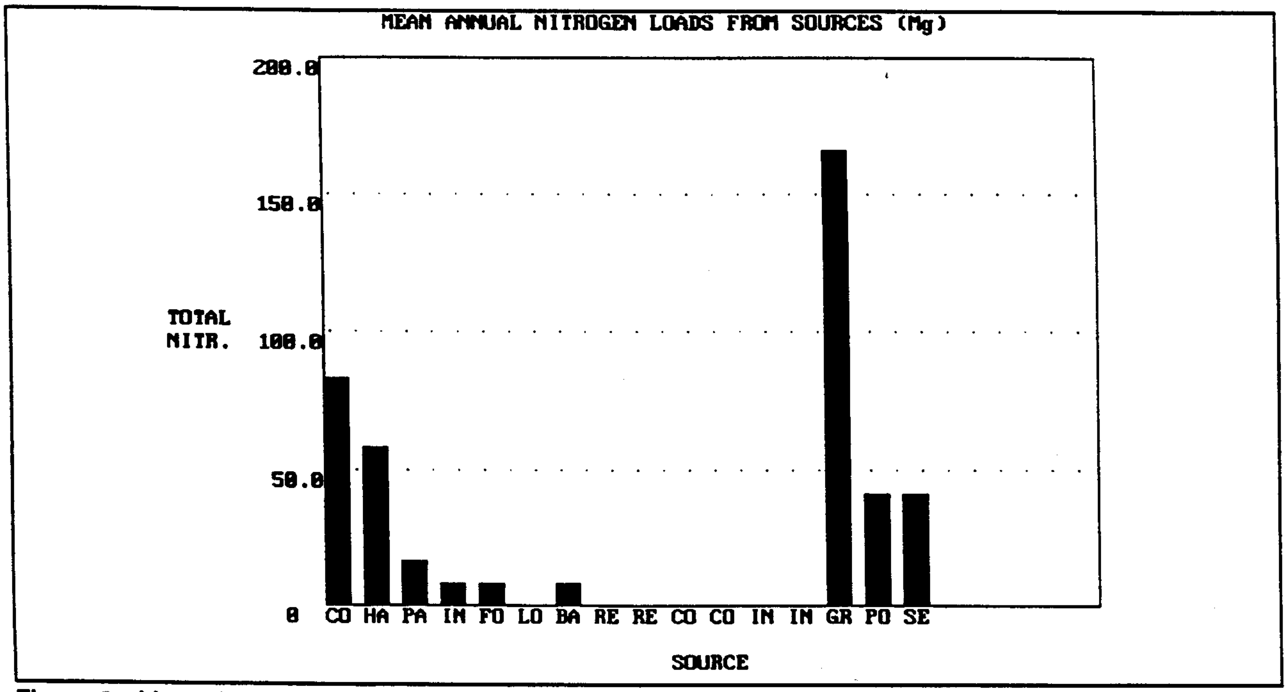

Figure 8. Mean Annual Nitrogen Load from Sources for 30-yr Simulation.

```
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.

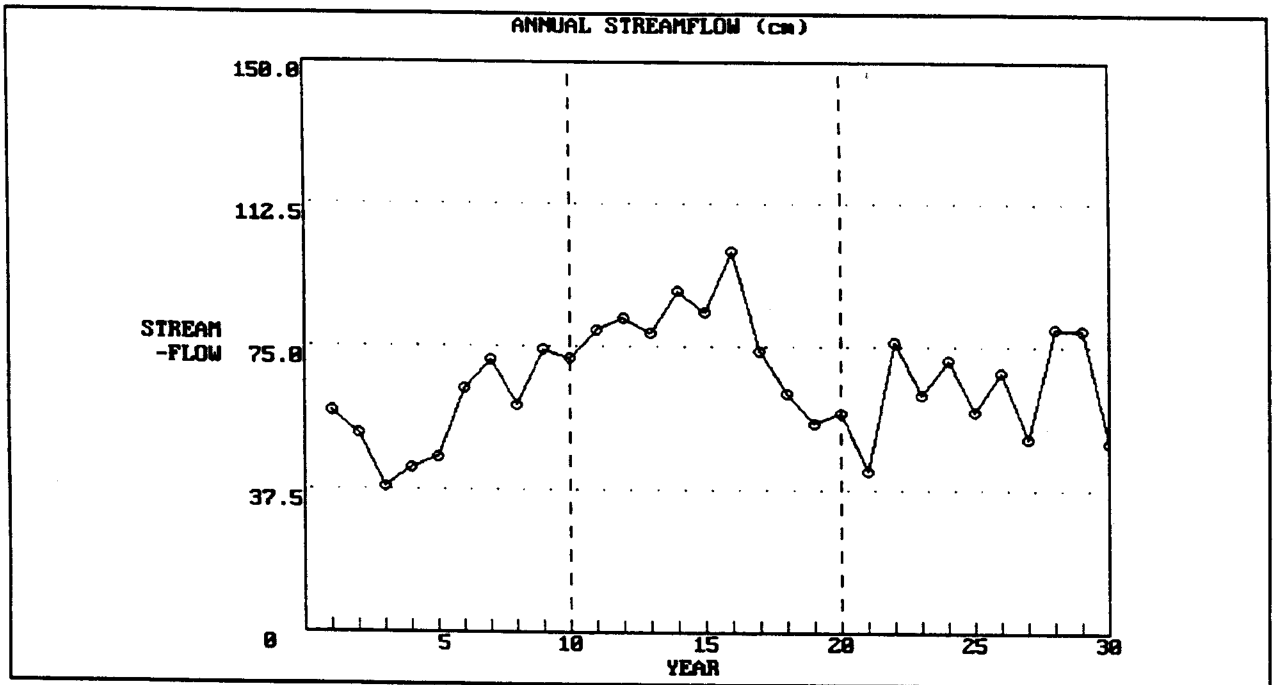

Figure 9. Annual Streamflows for 30-yr Simulation.

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

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

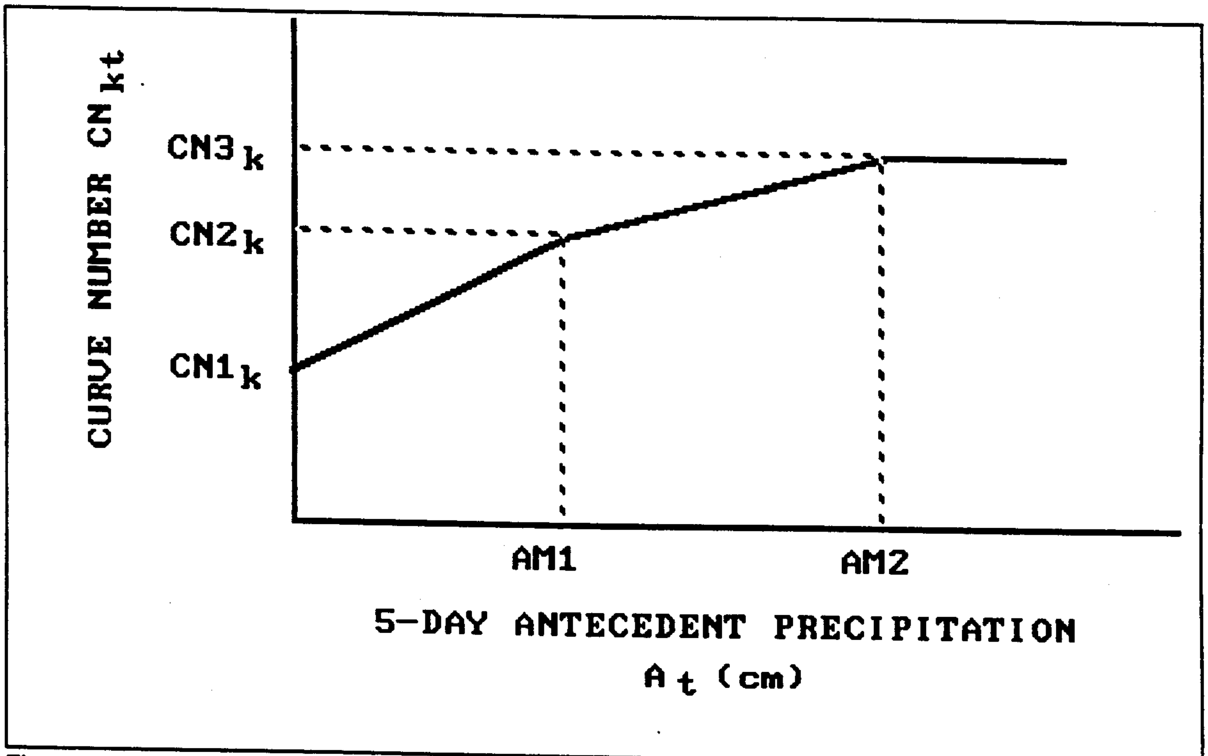

Figure A-1. Curve Number Selection as Function of Antecedent Moisture.

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 for 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 sediment yield (Mg), is TR_m/B_j. The total monthly yield is the sum of all contributions from preceding months:

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

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

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

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

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

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

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

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

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

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

or, for a time interval of one day,

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

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:

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

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

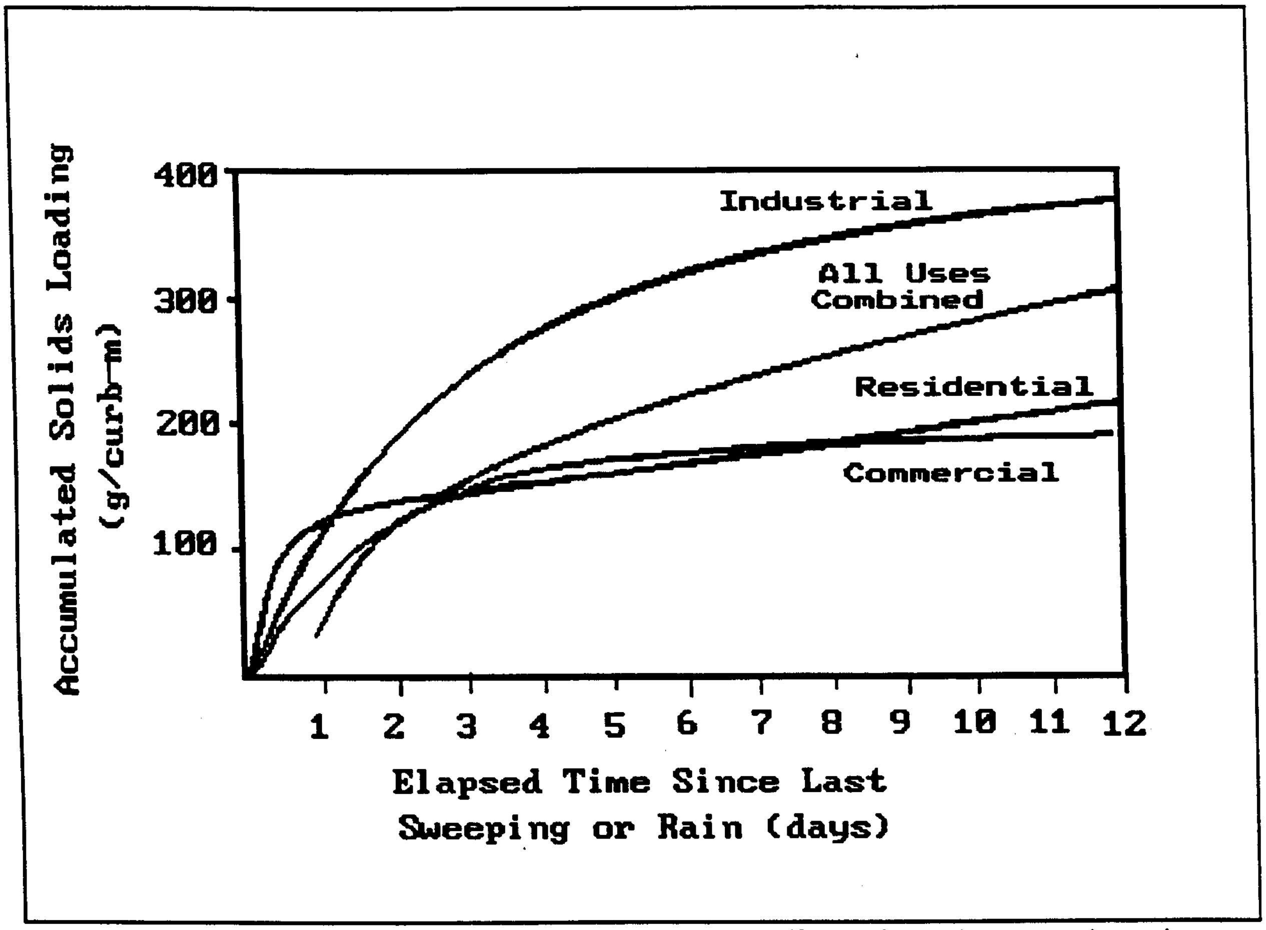

Figure A-2. Accumulation of Pollutants on Urban Surfaces (Sartor & Boyd, 1972; redrawn in Novotny & Chesters, 1981).

The runoff load is

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

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

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

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

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

Groundwater Sources

The monthly groundwater nutrient load to the stream is

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

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 ana deep saturated zones is similar

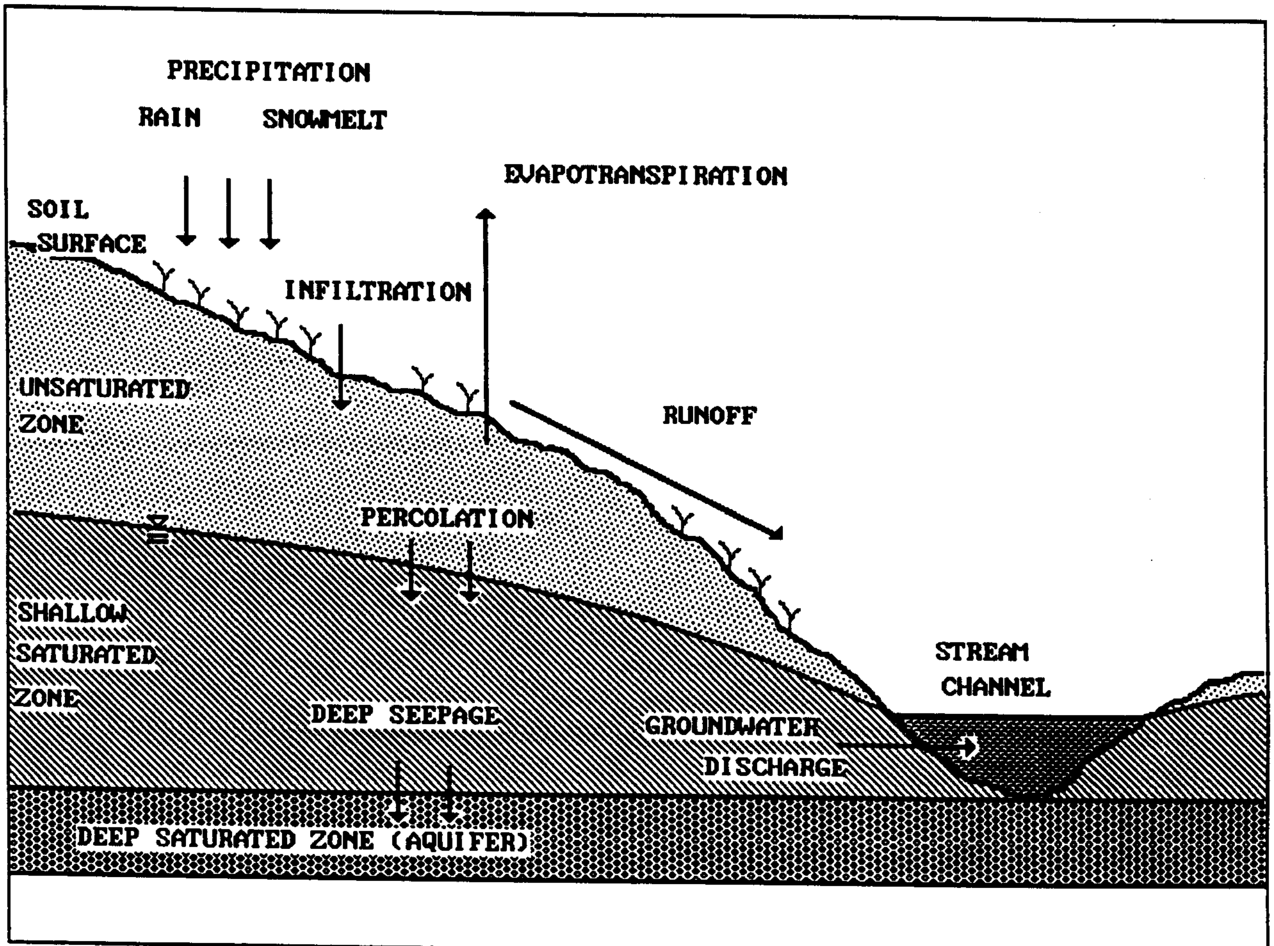

Figure A-3. Lumped Parameter Model for Groundwater Discharge.

to that used by Haan (1972).

Daily water balances for the unsaturated and shallow saturated zones are

$$U_{t+1} = U_t + R_t + M_t - Q_t - E_t - PC_t \quad \text{(A-27)}$$

$$S_{t+1} = S_t + PC_t - G_t - D_t \quad \text{(A-28)}$$

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):

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

Evapotranspiration is limited by available moisture in the unsaturated zone:

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

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

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

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):

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

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

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

and

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

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:

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

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

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

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

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

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).

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

$$\frac{dS}{dt} = -rS \qquad \text{(B-1)}$$

or,

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

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

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

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

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

The recession constant is thus given by

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

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_t 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.

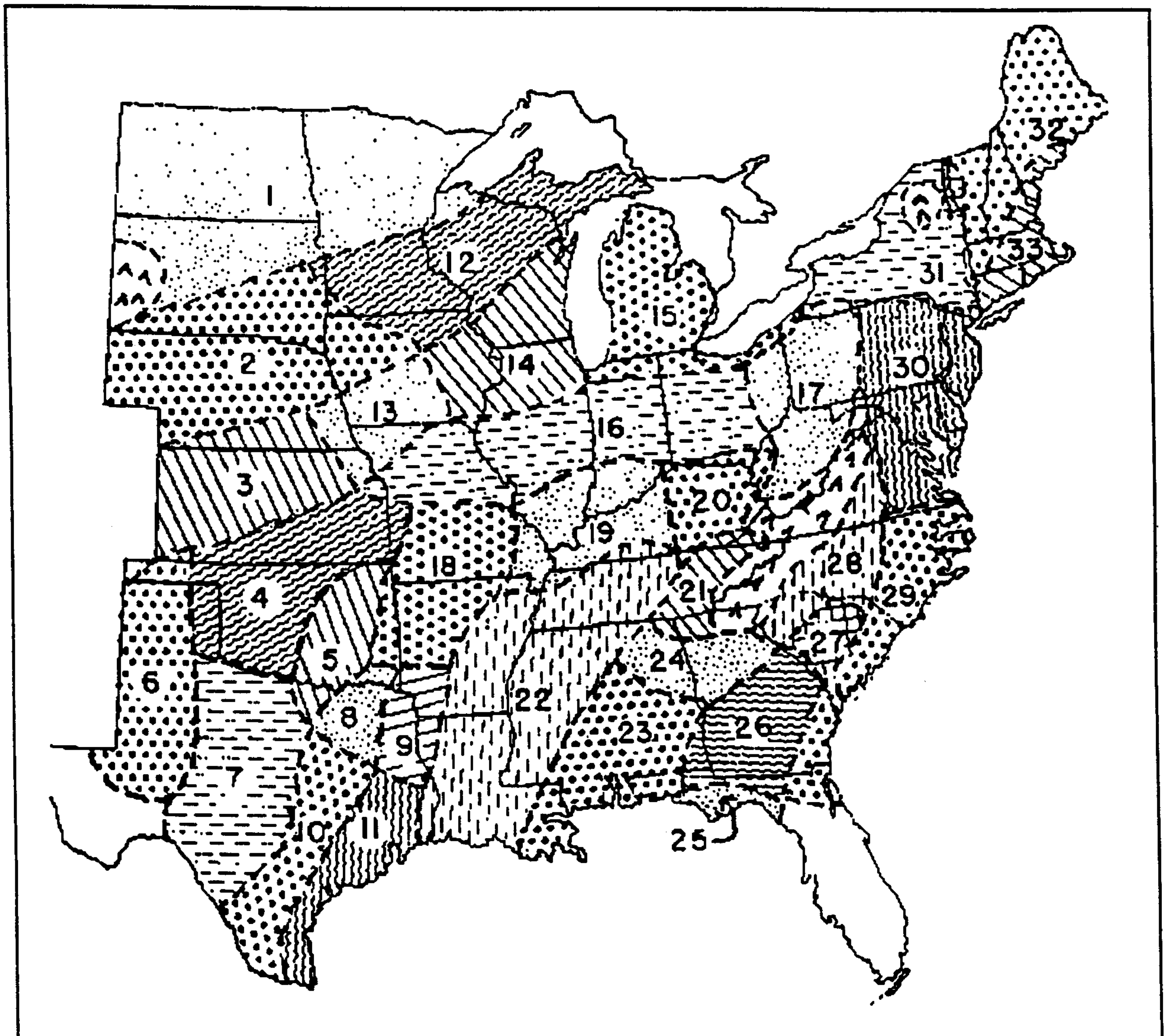

Figure B-1. Rainfall Erosivity Zones in Eastern U.S. (Wischmeier & Smith, 1978).

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

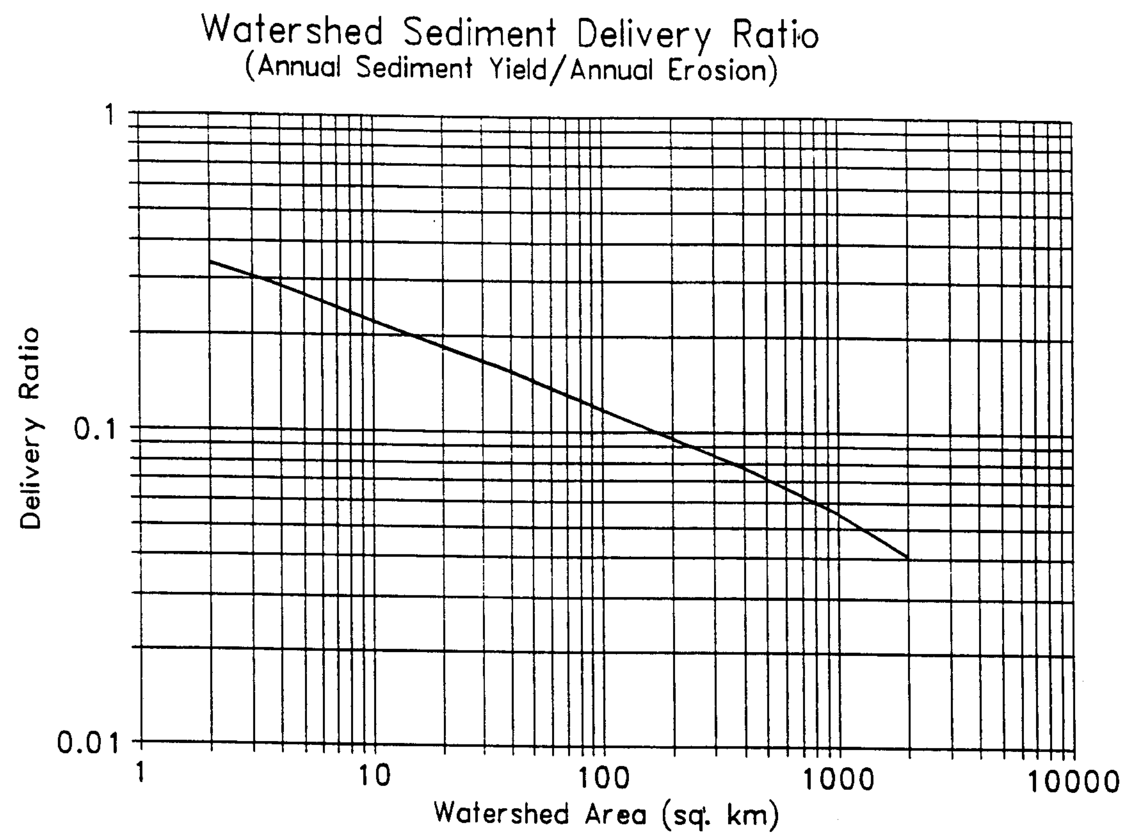

Figure B-2. Watershed Sediment Delivery Ratio (Vanoni, 1975).

Texture	Organic Matter Content (%) <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

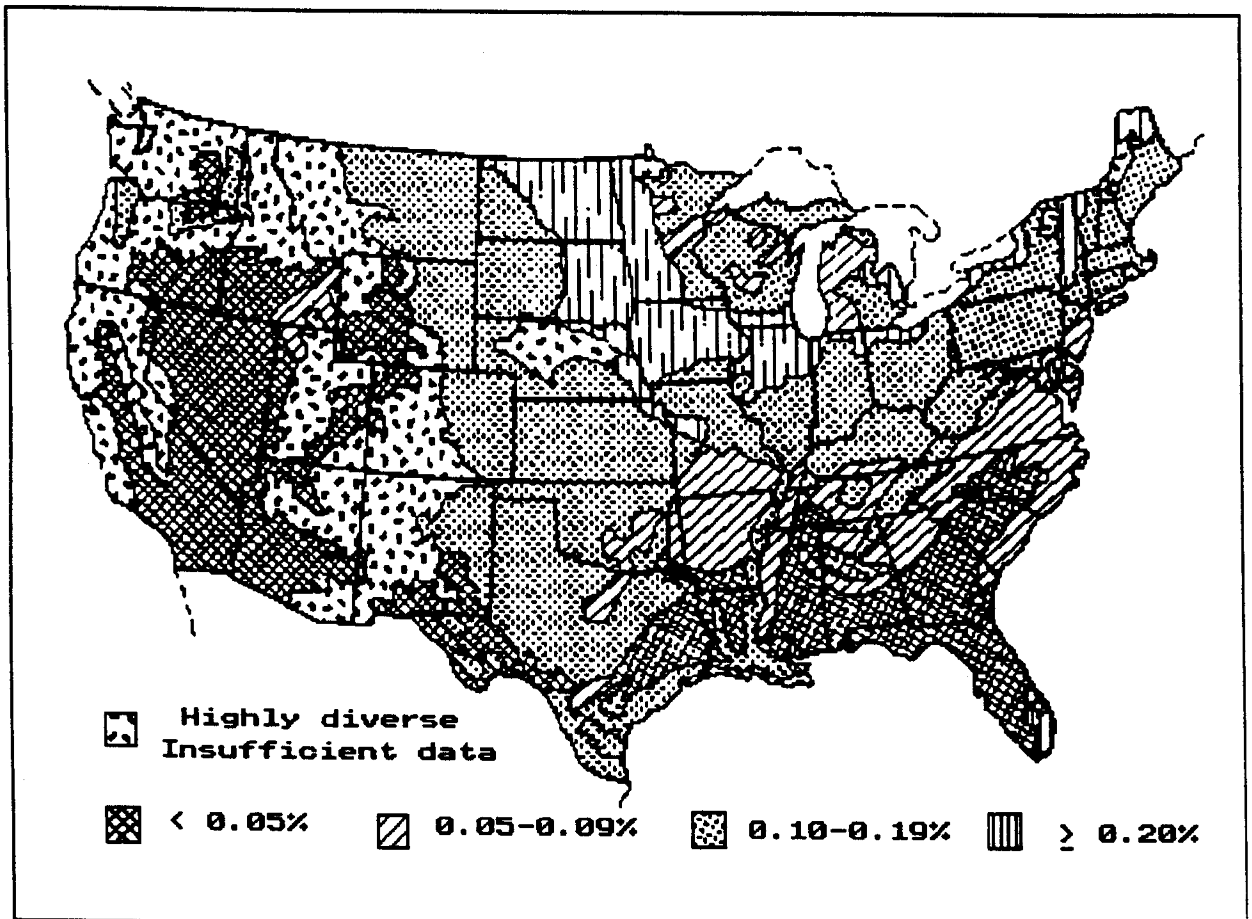

Figure B-3. Nitrogen in Surface 30 cm of Soils (Parker et al., 1946; Mills et al., 1985).

as the average soil nutrient content multiplied by an enrichment ratio. Soil nutrient levels can be determined from soil samples, soil surveys or general maps such as those given in Figures B-3 and B-4. A value of 2.0 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).

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

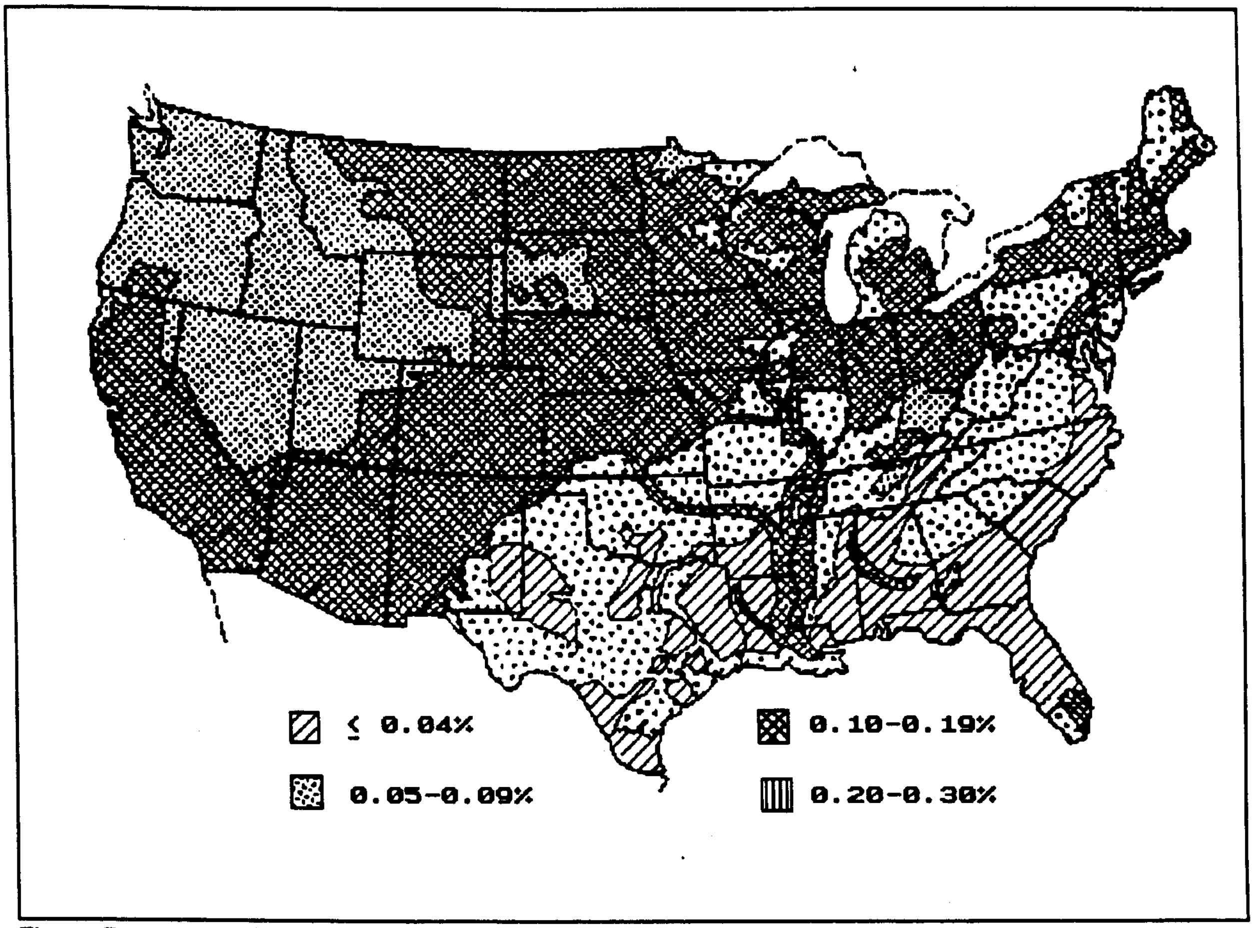

Figure B-4. P_2O_5 in Surface 30 cm of Soils (P_2O_5 is 44% phosphorus) (Parker et al., 1946; Mills et al., 1985).

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 ($\approx$ 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
Snowmelt runoff from manured land[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.
Nitrogen[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
Phosphorus[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	Sus-pended 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.

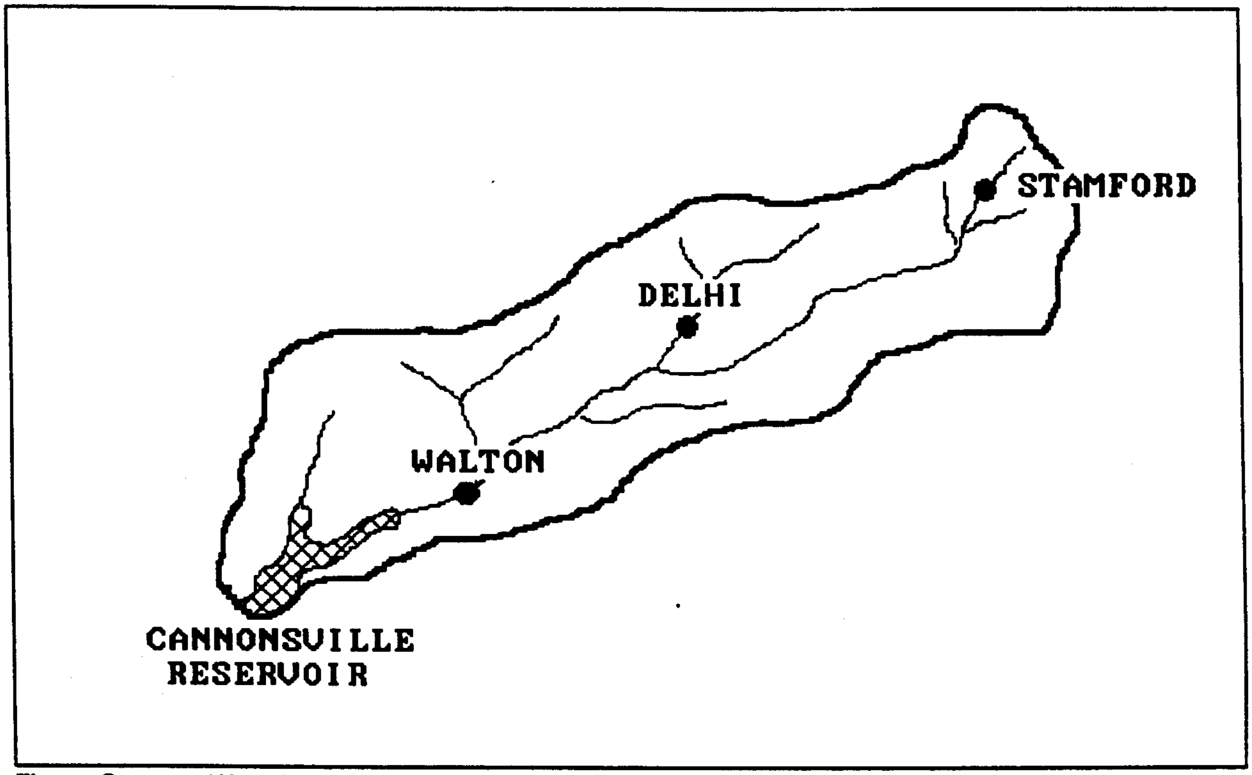

Figure C-1. West Branch Delaware River Watershed.

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. Cover factors (C) were selected Table B-10 based on several assumptions. For corn, the assumptions were that 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 Table 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

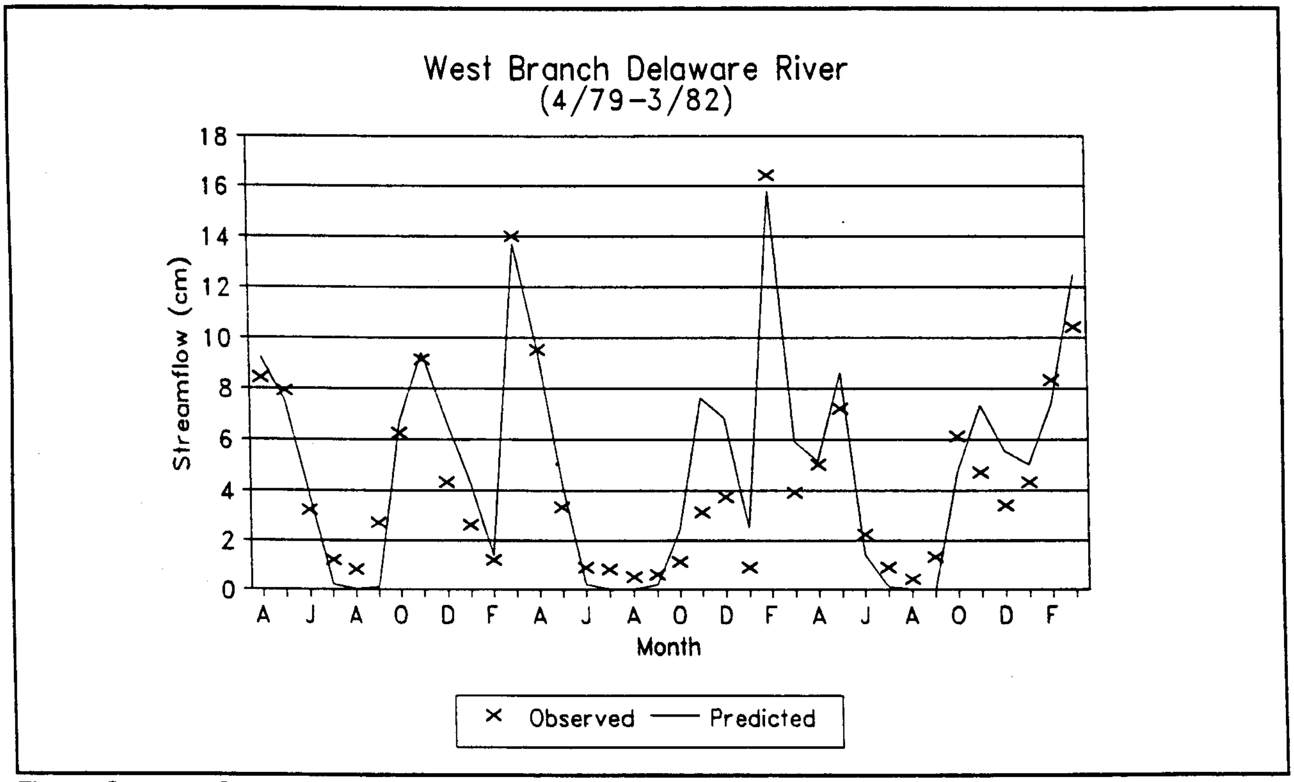

Figure C-2. Observed and Predicted Monthly Streamflow.

to the very simple lumped parameter groundwater model.

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.

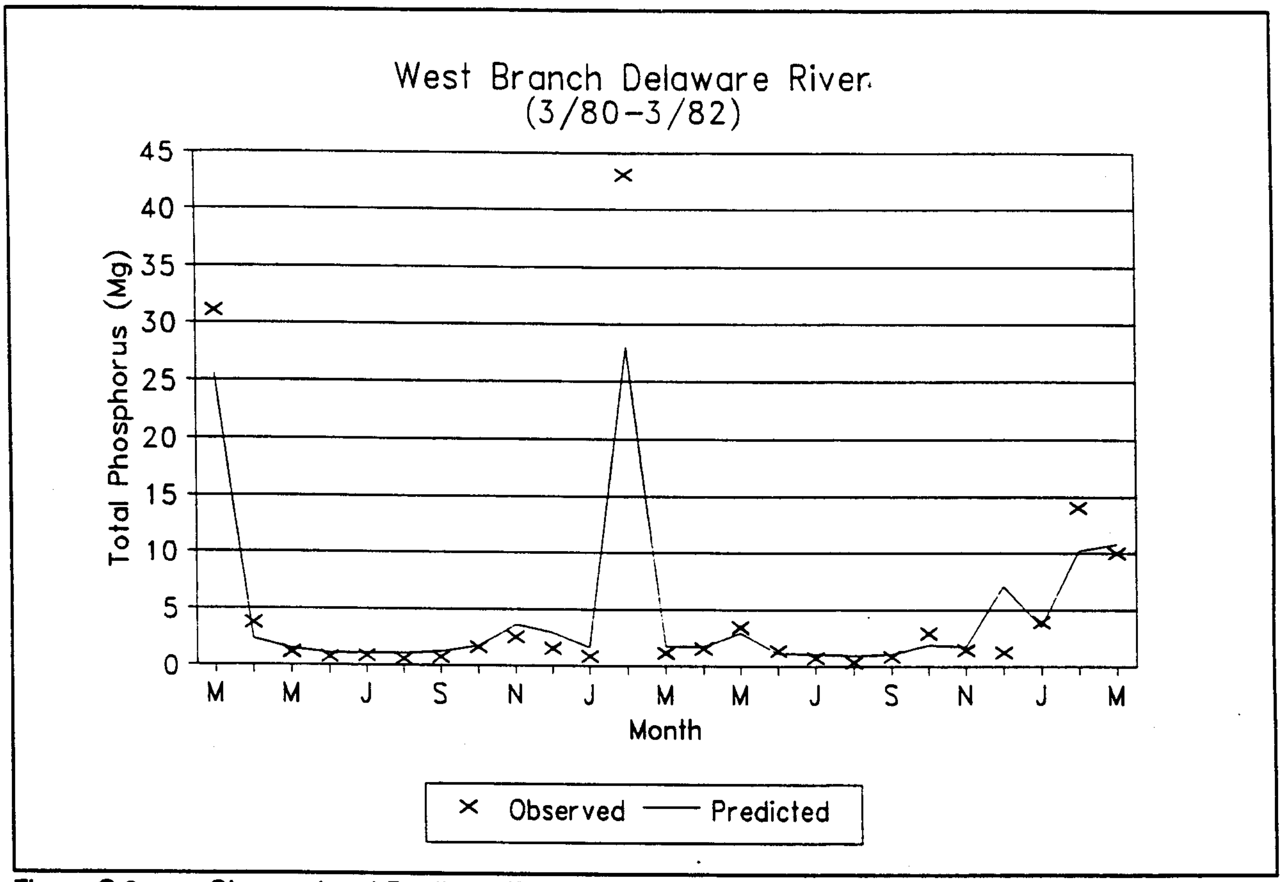

Figure C-3. Observed and Predicted Total Phosphorus in Streamflow.

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.

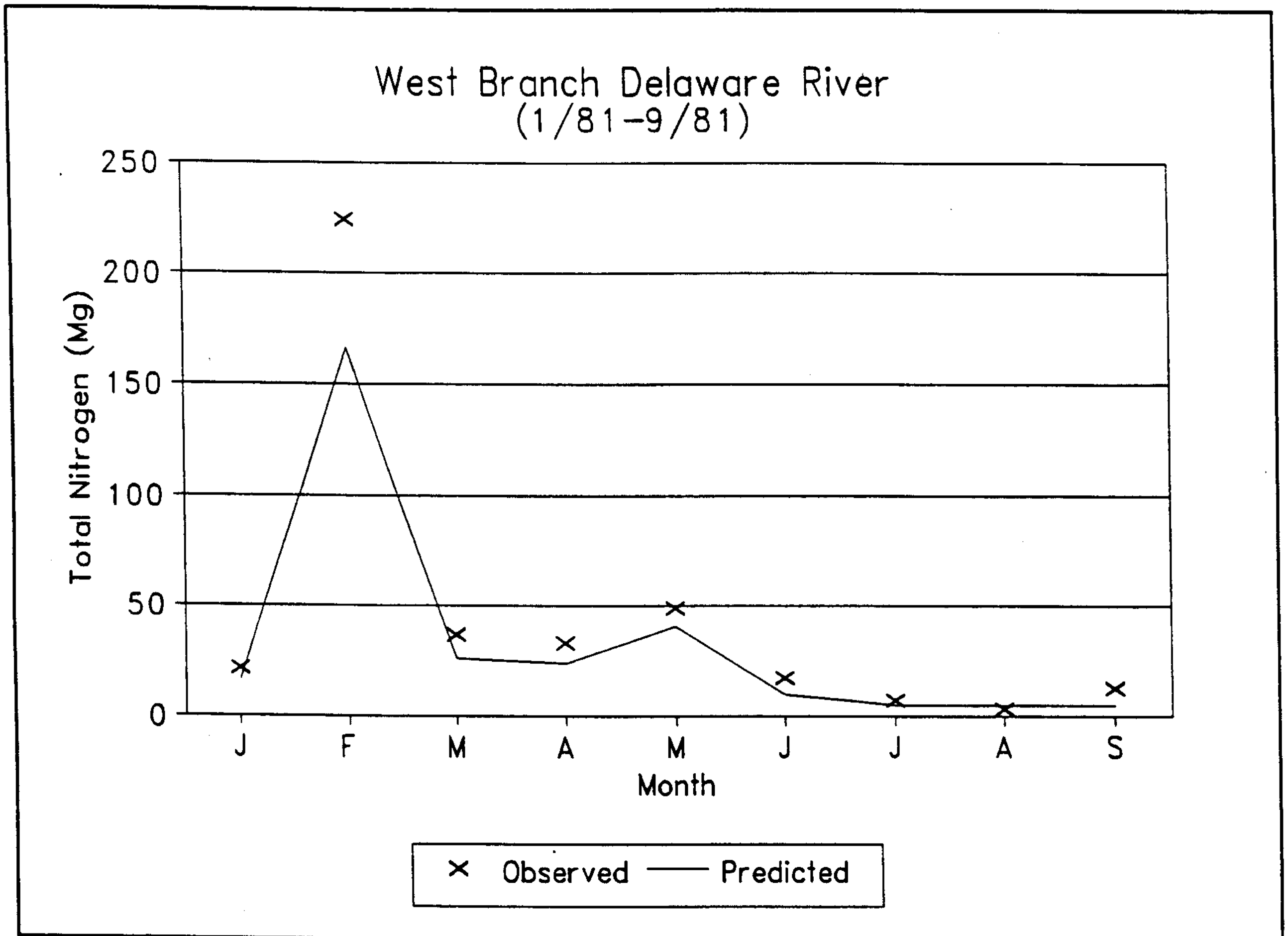

Figure C-4. Observed and Predicted Total Nitrogen in Streamflow.

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
"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
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7572,881,88,264
7572,881,88,264
9407,1094,109,328
9407,1094,109,328
9407,1094,109,328
7572,881,88,264
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```

WEATHER.DAT

```
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2,.4
-3,.1
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3,1
4,0
9,.4
2,.1
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4,0
12,.1
10,.6
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5,.1
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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 = 0.065

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 (ha)	RUNOFF (cm)	EROSION (Mg/ha)	DIS.NITR	TOT.NITR	DIS.PHOS	TOT.PHOS
				(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

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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 (ha)	RUNOFF (cm)	EROSION (Mg/ha)	DIS.NITR	TOT.NITR	DIS.PHOS	TOT.PHOS
				(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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