Application of a Watershed-Wide Nonpoint Source Pollutant Loading Model at Acadia National Park (Maine)

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EXECUTIVE SUMMARY

A study has been performed to investigate the applicability of a watershed-wide nonpoint source pollutant loading model at Acadia National Park (ANP) in Maine. Some of the primary objectives include: 1) Evaluation of existing watershed-wide nonpoint source pollutant loading models for their applicability to the geography at ANP and the specific needs of the National Park Service (NPS), 2) Selection of several representative watersheds and attempted application of the model, and 3) Development of a set of recommendations to strengthen modeling capability.

ANP is located along the central coast of Maine. This project considers the 30,000 acre Mount Desert Island area only. The Park sits atop bedrock; the soils are thin and bedrock fractures may be common. Hence the area's surface water resources are especially sensitive to the impact of watershed land use activity. Three watersheds were selected to represent the different basic land use categories. One (Old Mill Brook) is largely rural with some agricultural activity and residential areas; another (Marshall Brook Watershed) is comprised of a variety of land use types including rural, residential, commercial, and includes a closed landfill; the third (Upper Hadlock Brook Watershed) is the most pristine of the three, almost completely rural.

Nonpoint source loading models attempt to simulate watershed runoff processes during rainfall events and provide estimates of pollutant loadings to surface waters. A variety of models were evaluated for this study. A portion were lumped parameter models (e.g. HSPF; Donogian 1984), those which do not differentiate among the spatially varying processes which may contribute to runoff loadings, and others were distributed parameter models (e.g. AGNPS; Young, et al. 1978) which essentially divide the watershed into many small elements and utilize the finite difference procedure to solve for mass continuity throughout the watershed.

All of the distributed parameter models investigated were judged either too complex in terms of model set up and utilization as well as input data requirements or temporal capabilities were inadequate. Of the lumped parameter models, several appeared reasonable for the NPS objectives. Of these, GWLF (Generalized Watershed Loading Functions; Wu and Haith 1989) was determined as currently providing the most appropriate balance of level of difficulty and input data requirements.

GWLF is a menu driven hybrid model in that it follows the lumped parameter format, however, it additionally provides the ability to differentiate among land use types within the watershed with input and output ability for each land use type. Both continuous (seasonally and yearly) as well as short term (monthly) simulations are possible with the added ability to calibrate with data from specific wet weather runoff events. At present, GWLF can handle watershed erosion, sediment runoff, total and dissolved nitrogen and phosphorus as well as basic hydrological parameters. Model developers have indicated efforts directed toward a GIS interface.

Required input data were determined from United States Geological Survey topographic maps, field reconnaissance, and National Weather Service meteorological data. Simulations were performed for watershed erosion and sediment yield, and the nutrients nitrogen and phosphorus. In simulating current watershed conditions, results indicate mass loads from Old Mill Brook are more significant than mass loads from Upper Hadlock Brook. Likewise, model simulations regarding future development potential indicate Old Mill Brook as much more of an impact than Upper Hadlock Brook. Insufficient land use data for Marshall Brook watershed prevented any modeling to be performed.

CHAPTER 1
INTRODUCTION

1.1 Problem Statement

The role of nonpoint sources in the contamination of surface and groundwater bodies has received increasing attention. Nonpoint or diffuse pollution is generally associated with the use or misuse of land. According to Novotny (1988), land used for food production, construction, and urban development pollute streams, rivers, lakes and hence impair their beneficial uses. This contamination is often a result of a failure to recognize the impact of changes in land use on water quality.

In recognition of diffuse pollution, the National Park Service (NPS) has requested the application of a watershed-wide nonpoint source pollutant loading model at Acadia National Park in Maine. Using the model, the NPS is interested in developing some capability of predicting future water quality impacts from land use changes in response to development activities.

Of the several ways in which land use can impact water quality, two of the more important ones are surface runoff and infiltration. Surface runoff during a rain event can introduce various amounts of pollutants directly into the receiving waters. In the long term, infiltration into the ground can contaminate water supplies and have a lasting impact on the quality of surface streams which are fed by the subsurface flow.

Nonpoint source models attempt to mimic the effects of diffuse runoff on water resources in terms of mass loadings or concentrations of contaminants. Therefore, the successful model will not only serve as a mechanism for identifying stressed park ecosystems due to urbanization, but it will also allow park planners to foresee, and hopefully avoid, adverse future water quality impacts.

1.2 Study Area

Acadia National Park consists of approximately 35,000 acres located along coastal Maine in Hancock and Knox counties (see Figure 1-1). The principal holdings include approximately 30,000 acres on Mount Desert Island, 3,000 acres on Isle au Haut, and 2,000 acres on the

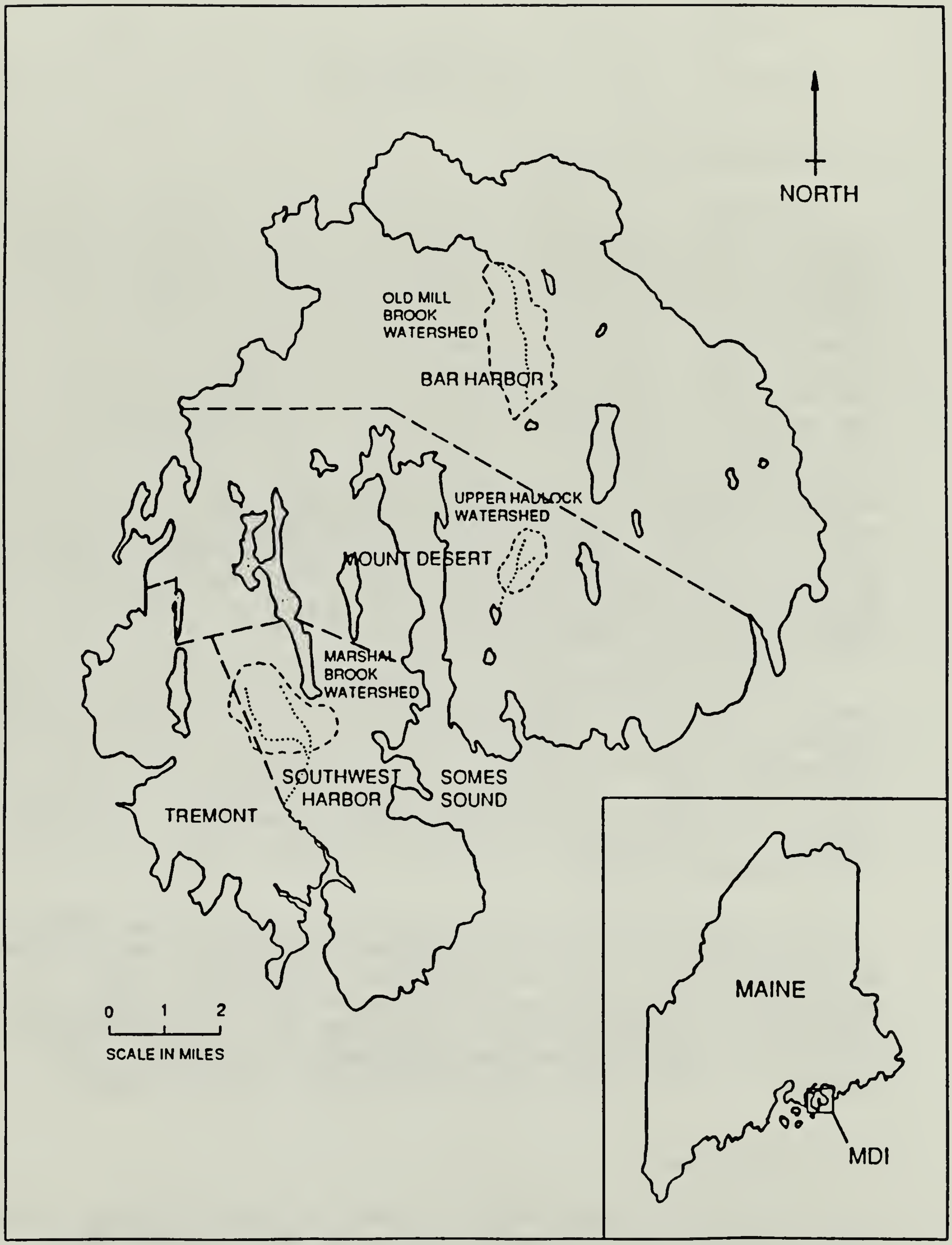

Figure 1-1. Mount Desert Island, Maine with three study watersheds indicated.

Schoodic Peninsula (NPS, 1991). This project considers the Mount Desert Island (Hancock County) component of the Park's holdings only.

1.3 Objectives

The original intent of this study was to provide park managers with a computer simulation model capable of predicting the impacts that watershed development will have on surface, and perhaps, groundwater quality in terms of mass loads. The study was to evaluate existing water quality and flow data for the Mt. Desert Island region and incorporate these data in an existing watershed simulation model followed by calibration under wet weather conditions.

During the course of the study, however, it became apparent that some of the initial goals of the study would not be attainable due to the lack of sufficient water quality and flow data in the Mt. Desert Island region during dry and wet weather conditions. Given the timing and economic resources of this study, a comprehensive field effort was not possible nor ever anticipated. In light of this, the objectives were revised to reflect the lack of available data yet tailored to provide a solid foundation upon which future work would benefit.

The overall objectives of this study are to provide park managers with an adaptation of an existing model capable of predicting the impacts that watershed development will have on surface water quality. The specific objectives are as follows:

1) Evaluate existing watershed-wide nonpoint source pollutant loading models for their applicability to the geography of Acadia National Park and the needs of the National Park Service. Rank the top few models in order of appropriateness to Acadia.

2) Select several representative watersheds on Mt. Desert Island and perform several flow monitoring and water quality sampling surveys to determine background conditions for several constituents.

3) Apply the model in a continuous fashion using annual weather records available from the National Weather Service (NWS) for the selected watersheds.

4) Determine the capability of the model to interface with the Park Service's GIS system (ArcInfo).

5) Provide recommendations for additional data

sets needed to strengthen the capability of the selected model.

CHAPTER 2
NONPOINT SOURCE MODEL REVIEW AND EVALUATION

In this section, several different modeling strategies are described. Nonpoint source pollution models utilize various methods in order to simulate watershed response to precipitation. Some models are primarily concerned with the short-term impacts of watersheds to isolated rain events, while others are geared towards long-term (seasonal, annual, multi-year) simulations. Parts of the discussion of these different modeling concepts presented in Sections 2.1 and 2.2 are based on excerpts from the works of Mills (et al., 1985), Novotny (1986), Beasely (1986), Huber and Heaney (1980), and Woolhiser (1973).

Precipitation is the driving force behind nonpoint source pollution. As indicated in Figure 2-1, precipitation comes into contact with a "pollutant" located on the land surface or within the soil. Portions of the pollutant, or pollutants, are transported in runoff and infiltrated to streams and groundwater aquifers. Because nonpoint source pollution is associated with random hydrologic events which yield dispersed drainage patterns, the determination of resulting pollutant loadings require sophisticated monitoring methods, especially during wet weather. The use of computer simulation models has become an important means of estimating runoff mass loadings (Mills et al., 1985).

Nonpoint source simulation models are part of a category of loading models which describe primarily formation of runoff and generation of pollutants from a source area. They can be divided into continuous simulation models or event oriented models. They also can be based on the distributive parameter or lumped parameter concept. In scope, they range from small field size application models to mostly deterministic, process-oriented, large watershed models. The available models range from simple application of the Universal Soil Loss Equation (USLE) with estimated enrichment ratios, to medium complexity models that use a simple hydrologic component, to multiple parameter, multicomponent models requiring extensive computing power and considerable amount of field data for calibration. Models have been developed to simulate hydrology, erosion and sediment process, nutrient (fertilizer) losses, and transport of organic chemicals from a variety of different land use types (Novotny, 1986).

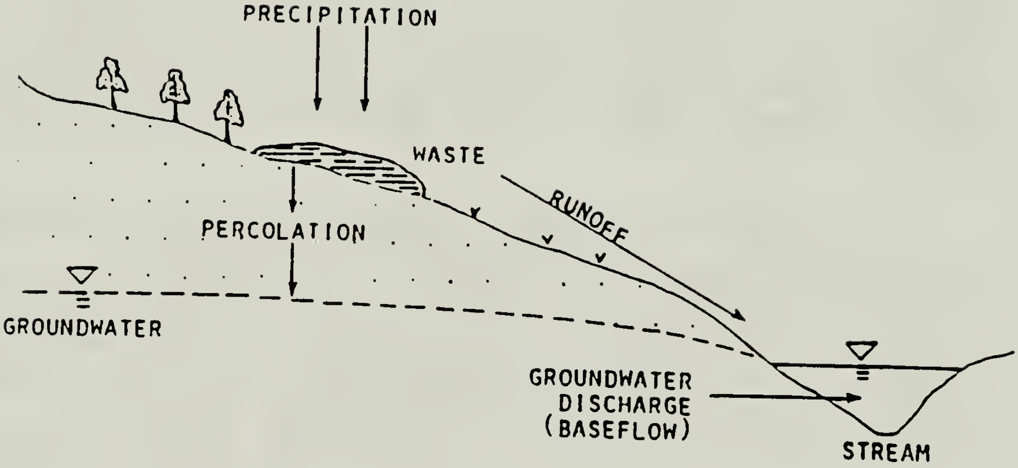

Figure 2-1. Some mechanisms of non point source pollution generation (from Mills et al., 1985).

2.1 Types of Models:

Nonpoint pollution simulation models generally fall into two categories: so-called screening models and hydrological assessment models.

2.1.1 Screening Models:

Screening models are usually simple tools which identify problem areas in a large basin. These models usually rely on assignment of unit loads of pollution to the various lands within the watershed. A unit loading is a simple value or function expressing pollution generation per unit area and unit time for each typical land use. The loads are typically expressed in units of mass/area-time (e.g. pounds/acre-year or kilograms/hectare-year) (Novotny, 1986).

Despite its questionable accuracy, the concept of relating pollution loading to land use categories has found wide application in area-wide pollution abatement efforts and planning. One reason explains this popularity: the concept provides a simple mechanism and quick answers to pollution problems of large areas where more complicated efforts would fail because of the enormous amounts of information required. The land/use pollutant loading is also compatible with so called "overview modeling", whereby unit loadings are combined with information on land use, soil distribution, and other characteristics to yield watershed loadings, or to identify areas producing or causing the highest amount of nonpoint pollution (Novotny, 1986).

Use of the unit load concept presumes that an adequate inventory of land data is available from maps, aerial and terrestrial surveys, remote surveys, and local information. The loading concept is applicable - in most cases - to long term estimates such as average annual loading figures (Novotny, 1986).

2.1.2 Hydrological Assessment Models:

Hydrological assessment models provide for two approaches to modeling nonpoint pollution. The most common are the lumped parameter models while some more complex models are based on the distributed parameter concept. Distributed parameter models often allow for more detailed descriptions of the watershed (Novotny, 1986).

2.1.2.1. Lumped Parameter Models:

The lumped parameter models, such as the Storm Water Management Model (SWMM), the Hydrological Simulation Model - FORTRAN (HSPF), the Nonpoint Source Pollution Model (NPS) and Chemicals, Runoff, Erosion from Agricultural Management Systems Model (CREAMS) to name a few, treat the watershed or a large portion of it as one unit. The various characteristics of the unit are then lumped together, often with the use of an empirical equation, and the final form and magnitude of the parameters are simplified to represent the model unit as a uniform homogenous system (Novotny, 1986).

A concept of a lumped hydrological nonpoint pollution model is shown in Figure 2-2. Flow within a specific unit may overflow either as drainage or to an adjacent unit.

Most watershed models are "lumped" in nature and describe an overall or average response of the watershed (Woolhiser, 1973). Since nonpoint sources are, by definition, spatially variable, lumped parameter models must rely on calibration to accurately describe the physical situation and to offset the inability of the model to take into account spatially varying processes (Beasely, 1986). The calibration process is used to determine the magnitude of certain input parameters in order to achieve the most accurate simulation of the physical processes occurring within the watershed (Novotny, 1986). However, calibration data is very rare and is not very useful when the watershed under consideration is being extensively modified. This may pose a problem in lumped parameter models. In addition, a model calibrated to a particular watershed is generally not transferable to another watershed unless the drainage areas are essentially identical in all respects (a highly unlikely eventuality) (Beasely, 1986).

Users of this type of model usually overcome any of the random nature of the inputs and system parameters by performing a sensitivity analysis on the model, whereby the magnitudes of the most significant inputs and system parameters are changed within their probabilistic boundaries and the response of the model to these changes provides an estimate of the ranges of the output (Novotny, 1986). Theoretically, the lumped parameter model can provide only one output location (Novotny, 1986).

Often times, watersheds are broken up into subcatchments in order to provide the lumped parameter model with a more accurate description of the spatial characteristics of the entire basin. This practice can potentially increase the accuracy of the initial response

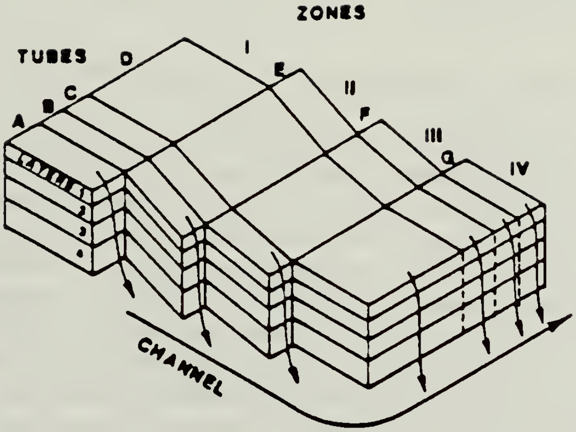

Figure 2-2. Lumped parameter model concept (from Novotny, 1986).

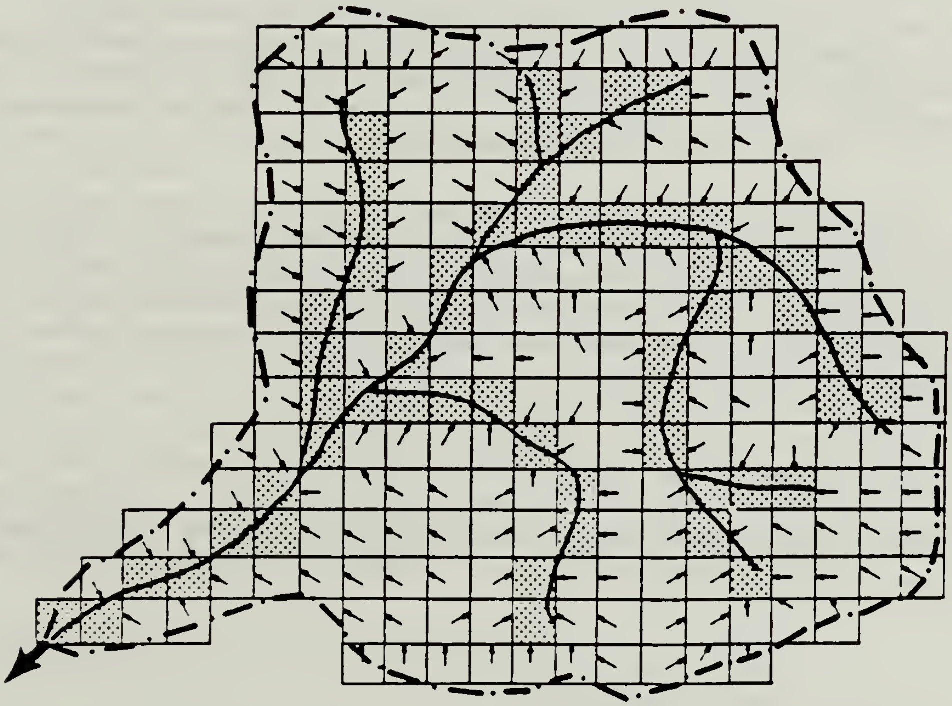

Figure 2-3. Distributed parameter model concept (from Novotny, 1986).

of the model to the original input parameters. If the initial simulation is in good agreement with measured values, the calibration effort is reduced to a small scale "fine tuning" operation.

2.1.2.2 Distributed Parameter Models:

The distributed parameter models, such as the Areal Nonpoint Source Watershed Environmental Response Simulation (ANSWERS) and the Agricultural Nonpoint Source Model (AGNPS), divide the system into very small finite elements as shown in Figure 2-3. Each element has uniform system parameters, soils, imperviousness, crop, slope, etc. The mathematical foundation of these models commonly uses the finite difference (element) representation of the basic differential equation governing the flow and mass continuity and motion in one, two or even three dimensions (Novotny, 1986).

Outputs can be obtained throughout the system from distributed parameter models, that is, from each element. This feature of distributed parameter models is one of their primary benefits, since areal loading maps and graphics can be generated by the computer. Distributed parameter models require large computer storage and extensive description of the system parameters, which must be provided for each unit. However, changes in the watershed and their effect on the output can be modeled easily and more effectively (Novotny, 1986).

Distributive parameter models provide the user with the ability to describe accurately the effects of changing topography, land use, management, soil responses and meteorological inputs, thus being able to discern the varying impacts of watershed modifications made in different places.

2.2 Time Properties:

There are basically two temporal scales in which models can be designed to run: on an event or continuous basis.

2.2.1 Event Modeling:

Discrete event modeling simulates the response of a watershed to a major rainfall or snowfall event. The principle advantage of event modeling over continuous simulation is that it requires relatively little meteorological data and can be operated with a shorter computer run time. The principle disadvantage of event modeling is that it requires specification of the design storm and antecedent moisture conditions, thereby assuming equivalence between the recurrence interval of the storm and the recurrence interval of the runoff (Novotny, 1986).

Event oriented models are advantageous and proper for comparative analyses of impacts of various land management and pollution mitigation practices on water quality for predetermined (extreme or average) conditions. Event simulation facilitates the calibration process of the model to a specific watershed because event models typically provide hydrographs (streamflow vs. time) and pollutographs (constituent mass loads vs. time) which can be compared directly to field observations. Such models are not designed for estimation of long term loadings of pollutants to a receiving water body. Distributed parameter models due to their discretization of parameters and hence, large computational time (CPU) requirements can be mostly run for a single event, or at most, a small series thereof (Novotny, 1986).

2.2.2 Continuous Modeling:

Continuous modeling simulates all processes incorporated in the model sequentially. Such models usually operate on a long term basis, with typical time intervals ranging from about an hour to a day. Mass balances are continuously performed on water and pollutants in the system.

The principal advantage of continuous modeling is that it provides long-term series of water and pollutant loadings that can be analyzed statistically. With continuous simulation, estimates of seasonal and annual pollutant loads can be made. A principal disadvantage of continuous modeling is that it requires long simulation runs, and hence long computing time. This many cases limits the number of alternatives that can be investigated. It also requires historical data on precipitation often in less than hourly intervals, which is often difficult to obtain.

2.3 Nonpoint Pollution Models in Current Use:

In accordance with the project objectives, an evaluation of existing models was completed to identify models which might be readily adapted for use in a rural land use setting such as in Acadia National Park. From a large number of models that have been developed in the United States in the last fifteen years, this section focuses on those that are in practical use and/or have been used by practitioners for managing nonpoint pollution from a variety of different land use types. Only models which are documented and currently maintained and have been practically applied with success are presented.

Table 2-1 (Donigian and Beyerlein, 1985) was used as a preliminary means of assessing possible models to be applied in this study. The purpose of this table is to provide an efficient manner in which to review the capabilities of the operational models in terms of their design characteristics.

Specifically, Table 2-1 relates eighteen models to the major characteristics which define most runoff problems. In this table, seven major problem characteristics - applicable land area, temporal properties, spatial properties, hydrology hydraulics, quality processes, data requirements and documentation - are subdivided into subheadings. The subheadings have been created to enable more distinction to be made among capabilities of various models. However, neither the seven major characteristics nor the subheadings represent all aspects of runoff problems (Huber and Heaney, 1980).

Based on Table 2-1, an analyst can develop two sets of information. One, for any given set of problems or problem aspects, a number of operational models can be identified. Two, for any given operational model identified in the tables, the problems that it can address can be easily identified along with other models capable of addressing the same problems. Although problems which models address can be identified using the tables, no information can be obtained from the tables as to how and with what level of specificity a model can analyze a given problem. Therefore, the table was used in conjunction with research to determine which models warranted further evaluation.

Four of the six models that were evaluated for this study are indicated in Table 2-1 under the Runoff Model heading. These models are NPS, HSPF, CREAMS, and ANSWERS. From the table, it was determined that these models were at least superficially compatible with the project directives. Each model satisfies the Forest/Natural criteria under the Land Use/Load Sources, which qualifies the models for application to rural land areas like those found on Mount Desert Island, Maine. The other characteristics of these four models as denoted by the table prompted further investigations into their design concepts. Appendices A, C, D and E provide complete descriptions of the model mechanics of these four models.

	LAND USE/LOAD SOURCES						HYDROLOGY			WATER QUALITY			TIME SCALE			DATA NEEDS			SPACE SCALE	
	Urban	Agriculture	Forest/Natural	Mining	Precipitation	Chemical Application	Surface Runoff	Subsurface Flow	Snowmelt	Sediments	Nutrients	Pesticides/Toxics	Annual Loads	Event Loads	Continuous Simulation	Detailed	Moderate	Minimal	Segmented/ Multiple Catchments	Lumped/ Single Catchment	Use, Documentation, Support
LOADING/SCREENING PROCEDURES																					
Hydroscience	●						●		●		●		●					●		●	A/M
EPA Screening Procedures	●	●	●		●					●	●	●	●	●				●		●	A
WRENS			●				●		●	●	●	●	●					●	●		A
WLFNPS		●	●				●		●	●	●			●			●		●		M/A
SWMM - Level I	●						●	○		●	●		●				●			●	A
RUNOFF MODELS																					
Simplified SWMM	●						●				●			●	●		●		●		M
ARM		●				●	●	●	●	●	●	●		●	●	●				●	E/A
NPS	●	●	●				●	●	●	●	●			●	●	●			●		E/A
HSPF/PERLND & IMPLND	●	●	●	●	○	●	●	●	●	●	●	●		●	●	●			●		E
CREAMS/CREAMS 2		●	●			●	●			●	●	●		●	●	●				●	E
ANSWERS		●	●	●			●	●		●	●			●		●			●		A
ACTMO		●				●	●	●	●	●	●	●		●	●	●			●		M
SWMM	●						●	○	●	●	●			●	●	●			●		E
STORM	●						●	○	●	●	●				●		●			●	E
MUNP	●						●			●	●			●			●			●	M
ILLUDAS/DRAINQUAL	●						●	●			●			●		●	●				A
DR3M	●				●		●	○		●					●	●			●		A
PRMS			●				●	●	●	●				●	●	●			●		A

Notes: ● - Capability included in model

○ - Capability not explicitly included but can be user-defined

Use/Documentation/Support

E - Extensive

A - Adequate

M - Minimal

Table 2-1. Applicability of Runoff Models to various problem contexts (from Donigian and Beyerlein 1985).

The remaining two models evaluated for this study are AGNPS and GWLF. Appendices B and F provide complete descriptions of the model mechanics for these three additional models. Chapter 4 evaluates each model with respect to its applicability to this study's directives.

CHAPTER 3
APPROACH AND METHODOLOGY

This chapter discusses the determination of the basic parameters necessary for model simulation in just about all models. In other more complex models, additional unique input parameters would be required. These unique parameters are not described here since most of the complex models were ruled out for the present study. Rather than investigate all of the intricate details of pollutant generation and transport in one watershed intensely, the goal was to use a model which could be readily applied to various watersheds without exorbitant data collection requirements. Other reasons are presented in Chapter 4.

3.1 Geographic/Physical Data:

Acadia National Park consists of approximately 35,000 acres located along coastal Maine in Hancock and Knox counties. This project considers the 30,000 acre Mount Desert Island (Hancock County) component of the Park's holdings only. Significant portions of many of the watersheds in Acadia National Park lie outside of the Park's boundary and are dependent upon state and local regulations to protect habitat and water quality (NPS, 1990). Most of the lakes and ponds within the Park are classified as low elevation oligotrophic waters with low buffering capacities (Davis et al., 1978).

Most of the Park is located on predominantly medium to course grained biotite and various granites (Kahl et al., 1985). Soils are generally thin and patchy with abundant areas of exposed bedrock. Watershed slopes are steep with a variety of vegetation types. The reader is referred to Kahl et al. (1985) for more information on soils and vegetation types.

3.1.1 Watershed Description and Delineation

To investigate all of the individual watersheds within the Park's holdings was beyond the scope of this project. Rather, a representative subgroup was selected which ranged from a chiefly undeveloped, pristine watershed, to more developed ones. In conjunction with NPS staff, these watersheds selected using the following criteria: (i) direct drainage to a major (perennial) stream system, (ii) a minimum area of approximately 350 acres which would preclude relatively small, minor streams that will normally have minimal or no flow during the dry season, (iii) the presence of major land use types of interest to the National Park Service and the surrounding townships, and (iv) the availability of historical baseline data as well as current water quantity and quality data.

Figure 1-1 shows this study's delineation of three selected watersheds on Mount Desert Island, Maine. The three watershed drainage basins were delineated using standard practice, namely connecting topographic high points and ridges on the appropriate 7.5 minute series United States Geological Survey (USGS) topographic quadrangles (quads) as described by Horton (1945). The three specific quads used during the delineation process were the Southwest Harbor Quad, the Bartlett Island Quad, and the Salsbury Cove Quad.

In accordance with the third selection criterion, the three chosen watersheds are representative of the various land use scenarios which coexist within the Mount Desert Island Region. The following is a brief and general description of the physical characteristics and points of interest within the three chosen watersheds:

Old Mill Brook Watershed:

This watershed is located in the northeastern portion of Mount Desert Island in the Town of Bar Harbor (year-round population as of 1990 = 4,424) as shown in Figure 1-1. Old Mill Brook drains from McFarland and Youngs Mountains (and other unnamed topographic high points) and flows north where it eventually feeds Northeast Creek, which in turn drains into Thomas Bay.

The basin is largely rural with a small agricultural component, but does include sections of urbanization (approximately 37 existing residences within the watershed, some clustered). All of these residences utilize septic systems. The National Park Service owns 34% of the watershed. Figure 3-1 shows the Old Mill Brook Watershed sampling site with the land owned by the National Park Service noted.

Aside from satisfying the selection criteria, this basin is of particular interest due to the proposed developments within the privately owned Acadian Farm located at the southern end of the watershed. With a large amount of proposed development, this sensitive area faces potential degradation from nonpoint source pollution. Earlier studies have been performed on a small portion of this watershed to predict the impact of such a development

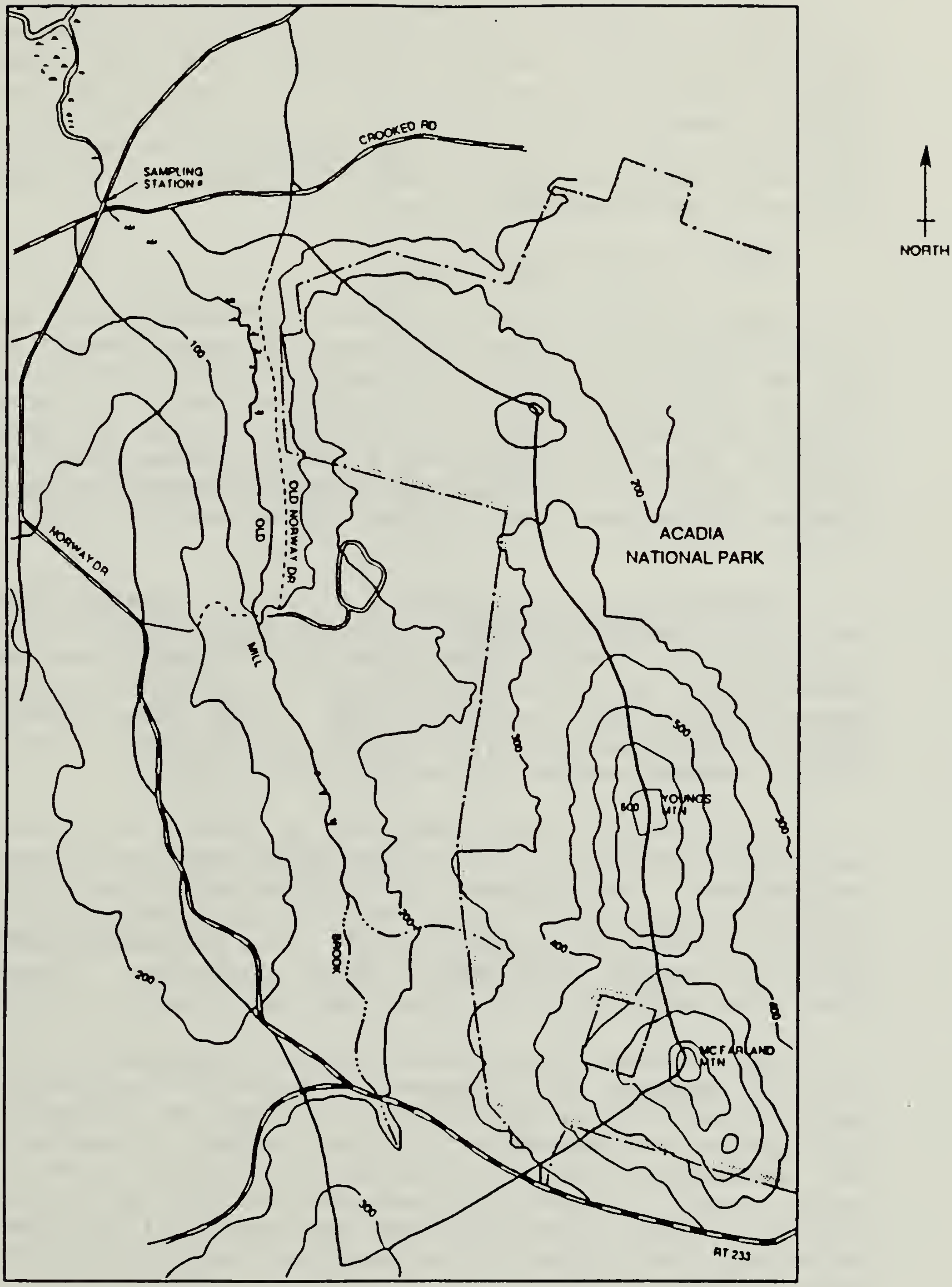

Figure 3-1. Old Mill Brook Watershed detail and location map.

(CES, 1985). However, there is no existing baseline flow and quality data to support a calibration endeavor.

This proposed development represents the exact type of situation in which an appropriate nonpoint pollution model would be applied in order to predict receiving water impacts due to the land use changes. Once these water quality impacts were quantitatively understood via the selected simulation model, decisions can be made concerning best management practices (BMPs) options for abatement before any detrimental impact.

Hadlock Brook Watershed:

Upper Hadlock Pond is located in the central portion of Mount Desert Island, just east of Somes Sound, in the Town of Mount Desert (year-round population as of 1990 = 1, 798) as shown in Figure 1-1. The catchment of interest is located to the northeast of the pond and is drained by the recently named Penobscot and Gilmore Brooks (Kahl et al., 1985). Below the confluence of Penobscot and Gilmore Brooks, the stream is referred to as Hadlock Brook (Heath, 1990).

Seventeen natural ponds or lakes in Acadia National Park larger than 10 acres, such as Upper Hadlock Pond, are classified as "great ponds" and were placed under the jurisdiction of the state by the "Great Ponds Ordinance of Massachusetts Bay" in 1641 - 1647. The Maine Department of Inland Fisheries and Wildlife has jurisdiction over all "great ponds" within the state (NPS, 1991).

The Hadlock Brook Watershed is nearly all rural with negligible amounts of urbanized land uses (no existing residences). Development within the watershed is limited to hiking trails and two gravel carriage paths constructed during the 1920's (Heath, 1990). The National Park Service owns 100% of the land within this watershed. Figure 3-2 shows the Hadlock Brook Watershed topographic features.

The Hadlock Brook Watershed is of particular interest not only because it represents a pristine and rural application for the model but also because it was included in a larger assessment of surface waters in Acadia National Park conducted from 1982 through 1988 (Kahl et al., 1985; Heath, 1990). These previous studies provide various degrees of data (both quality and quantity) for the watershed that aided in the eventual application of the selected model.

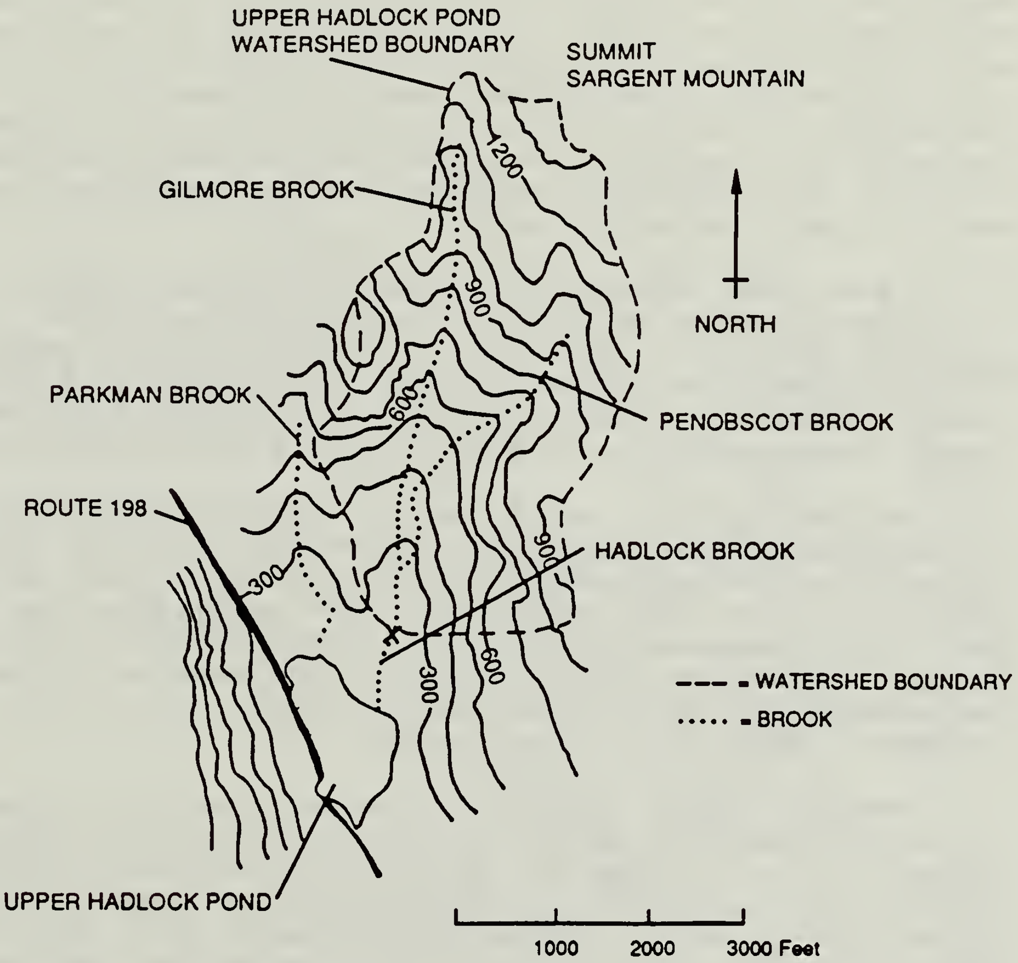

Figure 3-2. Hadlock Brook Watershed detail and location map.

Marshall Brook Watershed:

The Marshall Brook Watershed is located to the west of Somes Sound and just south of Long Pond in the Towns of Southwest Harbor (year-round population as of 1990 = 1,243) and Tremont (year-round population as of 1990 = 1,060) as shown in Figure 1-1. This is the most complex watershed because of its variety of land use types. The National Park Service owns 72% of the land within this watershed. The watershed includes rural sections (Park owned lands), urbanized residential areas (approximately 30 residences), and commercial areas (approximately 2 commercial structures). Most of these developments utilize septic systems. Approximately ten homes in the Long Pond Road vicinity are presently connected to the Southwest Harbor Waste Water Treatment Facility.

This basin also includes the Worcester landfill (located adjacent to the old Worcester dump) which is situated about 3000 feet south of Long Pond and about 600 feet northeast of Marshall Brook, located in Southwest Harbor, Maine, as shown in Figure 3-3. Finally, Marshall Brook Watershed includes most of the Worcester gravel pit.

Marshall Brook, which empties into the Atlantic Ocean at Bass Harbor, has been subject to pollution by leachate from the privately-owned Worcester landfill operating adjacent to the park boundary. Once considered one of the best trout streams in the area (Soukup and Mitchell, 1981), Marshall Brook has declined as a fishing water, reportedly because of impaired water quality resulting from the adjacent landfill (Gerber, 1985).

Hansen (1980b) reports decreased dissolved oxygen and elevated levels of un-ionized ammonia and other dissolved constituents. Subsequent studies by Soukup and Mitchell (1981), and Soukup et al. (1984) confirm these results and found that specific conductance, nitrate plus nitrite, total Kjeldahl nitrogen, chloride, potassium, and sodium were elevated in the main ditch draining the landfill and in affected downstream areas of Marshall Brook. The level of contamination was found to be severe enough to harm fisheries resources as well as other components of the native aquatic community.

According to Gerber (1982), Worcester's gravel pit has been the repository for stumps, brush, construction debris, and unauthorized dumping of trash. It has been suggested that the gravel pit could be adversely impacting groundwater within the watershed (Gerber, 1982).

Other studies by Gerber (1980, 1982, 1985a, and 1985b) and Sewall (1982) have yielded similar conclusions

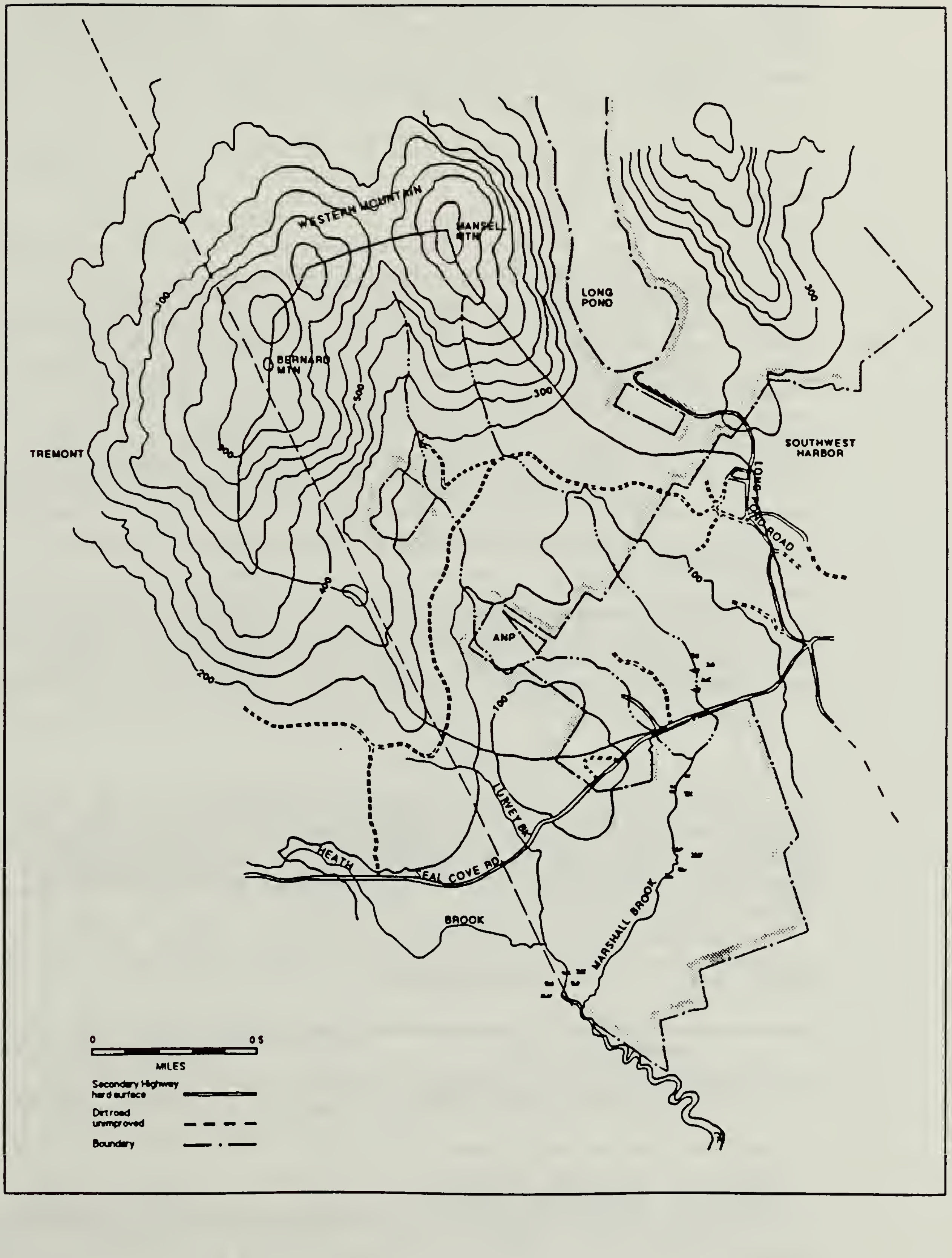

Figure 3-3. Marshall Brook Watershed detail and location map.

concerning the landfill's impact on Marshall Brook. However, a recent survey (Gerber, 1989) indicates that while there is continuing water quality improvement in Marshall Brook, concentrations of several constituents remain significantly elevated from background levels in ditches draining the landfill (NPS, 1991).

It is these two separate pollutant sources - the landfill (and old dump) and the gravel pit - which make the Marshall Brook Watershed a particularly interesting catchment to model. Although it is felt that Bass Harbor marsh is no longer being threatened by leachate emanating from the closed landfill site (Gerber, 1989), the National Park Service strongly supports the continuation of follow-up monitoring by the township, but does not believe further action is warranted at the present time (NPS, 1991). Unfortunately, all monitoring to date has been comprised of water quality sampling only. Without accompanying flow data, it becomes very difficult to develop mass loading rates in support of the modeling effort. The NPS is currently supporting a study to evaluate the ecological impacts of nutrient loading to the Bass Harbor Marsh system (Doering et al., 1991). Marshall Brook represents one of the nutrient sources being evaluated.

The following subsections will provide in depth descriptions of the specific physical characteristics of the individual watersheds which are necessary for the implementation of most nonpoint source simulation models.

3.1.2 Area Determination

Determination of the three watershed drainage areas was accomplished by a planimetering process (as noted in Section 3.1.1), using a Tamaya digital planimeter model Planix 5. The areas of the individual watersheds are listed in Table 3-1.

Table 3-1. Watershed Areas.

Watershed Name	Watershed Area
Old Mill Brook Watershed	1663.9 acres
Hadlock Brook Watershed	398.1 acres
Marshall Brook Watershed	1065.6 acres

Many nonpoint simulation models consider catchments to be grouped into three sizes: small (< 50 acres), medium (50-500 acres), and large (> 500 acres) (Huber and Heaney, 1980). In some cases, algorithms of specific models are designed to function within specified area limitations. Using these limits as a guide, two of the selected watersheds are of the large category and one in the medium category.

3.1.3 Baseflow Sampling Locations

As noted earlier, a comprehensive water quality and quantity sampling field program was never a part of the objectives of this study. However, in order to obtain an understanding of the current conditions of the streams within the selected watersheds, however sparse that may be, it was decided to perform some minimal baseflow sampling and stream flow determination. Baseflow is emphasized since sampling occurred in the absence of overland runoff. These data were not used for modeling purposes but gave a view of the differences of the three watersheds.

Three primary sampling stations coincided with the most downstream location of the major stream within each watershed (also known as design locations). In two of the watersheds, additional locations upstream of the design locations were established to determine relative differences. Three stations were gaged in the Hadlock Brook Watershed, one in the Old Mill Watershed, and two in the Marshall Brook Watershed. Table 3-2 describes the location of the monitoring stations.

The field hydrologic and water quality monitoring program was performed as discussed in section 3.3. Surface stream monitoring, which included both water quality data and stream flow data, was performed on two Fall trips (5, 6 October and 15, 16 November, 1990) and one Spring trip (20 May through 31 May). These data were not sufficient to be used for any model calibration efforts. It is hoped, however, that these data may be of value in future efforts.

3.1.4 Watershed Slopes

The mechanics of overland runoff are very sensitive to the slope of the watershed. Hence, details for its calculation are presented below.

The catchment slope should reflect the average along the pathway of overland flow to inlet locations. For a simple geometry the calculation is simply the elevation difference divided by the length of flow. For more complex

Table 3-2. Flow Monitoring Station Location Descriptions for the Current Study.

STATION		
NUMBER	NAME	LOCATION
1	Hadlock Brook	At the intersection of Hadlock Brook and the carriage road 1000 ft. NNE of Upper Hadlock Pond.
2	Upper Hadlock Brook (Right Fork)	100 ft. upstream of the fork in Hadlock Brook on the right side; the fork is located 2100 ft. NNE of Upper Hadlock Pond.
3	Upper Hadlock Brook (Left Fork)	100 ft. upstream of the fork in Hadlock Brook on the left side; the fork is located 2100 ft. NNE of Upper Hadlock Pond.
4	Old Mill Brook	Upstream headwall of cement culvert running beneath Norway Dr located at the intersection of Norway Dr and Crooked Rd.
5	Marshall Brook (East)	At culvert located at the eastern intersection of Marshall Brook and Seal Cove Road.
6	Marshall Brook (West)	At culvert located at the western intersection of Marshall Brook and Seal Cove Road.

geometries, several overland flow pathways may be delineated, their slopes determined, and a weighted slope computed using a path-length weighted average (Huber and Dickinson, 1988).

Alternatively, it may be sufficient to simulate what the user considers to be the hydraulically dominant slope for the conditions being simulated. This methodology was used to obtain the average watershed slopes for each of the three representative watersheds considered in this study. Other techniques are available in Chang, et al. (1989).

Using the appropriate 7.5-minute series USGS topographical quadrangles, elevations and flow lengths were determined and average slopes were calculated. The flow lengths were measured using a Keuffel & Esser Co. Map Measure line meter. The hydraulically dominant slopes were chosen such that the respective pathways included the primary and secondary streams within the watersheds. Several pathways extending from points of higher elevations to the stream locations and eventually to the sampling sites were delineated. The slopes determined from these pathways were then averaged (arithmetic mean) to reflect the representative watershed slope.

In the Old Mill Brook watershed, elevations range from 19.7 feet at the sampling station, to 725.1 feet at the summit of McFarland Hill. Three pathways were chosen, initiating at the peaks of Aunt Betty Hill (previously unnamed; see Figure 3-1), McFarland Hill, and Young's Mountain, respectively, and terminating at the sampling station.

The first pathway connects the summit of Aunt Betty Hill at an elevation of 380 feet to the sampling site via one of the two secondary streams which feed Old Mill Brook. This pathway measures 15,800 feet in horizontal distance, yielding a slope of 2.4%. The second pathway connects the summit of McFarland Hill at an elevation of 725.1 feet to the sampling site via the other secondary stream which feeds Old Mill Brook. This pathway measures 15,800 feet in horizontal distance, yielding a slope of 4.6%. The third pathway connects the summit of Young's Mountain at an elevation of 672.5 feet to the sampling site via Old Mill Brook. This pathway measures 13,000 feet in horizontal distance, yielding a slope of 5.2%. All three slopes were averaged to obtain the representative watershed slope of 4.1%.

Elevations in the Upper Hadlock Brook Watershed range from 258 feet at the sampling station, to 1,397 feet at the summit of Sargent Mountain. Two pathways were chosen, both initiating at the peak of Sargent Mountain and terminating at the sampling station.

The first pathway connects the summit and the sampling site via Penobscot Brook, yielding a horizontal distance of 8,000 feet and a slope of 14.2%. The second pathway follows the Gilmore Brook channel, measuring 7,800 feet in length and yielding a slope of 14.6%. These slopes were averaged to obtain the representative watershed slope of 14.4%. A previous study on the Upper Hadlock Brook watershed by Heath (1990) included a gradient value for Hadlock Brook of 0.11 m/100m (11%).

Elevations in the Marshall Brook Watershed range from 60 feet at the sampling station, to 1000 feet at the summit of Bernard Mountain. Three pathways were chosen, initiating at the peaks of Mansel Mountain, Knight Nubble, and Bernard Mountain, respectively, and terminating at the sampling station.

The first pathway connects the summit of Mansel Mountain at an elevation of 938 feet to the sampling site via the east branch of Marshall Brook. This pathway measures 9,000 feet in horizontal distance, yielding a slope of 9.8%. The second pathway connects the summit of Knight Nubble an elevation of 960 feet to the sampling site via the west branch of Marshall Brook.. This pathway measures 10,700 feet in horizontal distance, yielding a slope of 8.4%. The third pathway connects the summit of Bernard Mountain at an elevation of 1000 feet to the sampling site via the west branch of Marshall Brook. This pathway measures 9,800 feet in horizontal distance, yielding a slope of 9.6%. These slopes were averaged to obtain the representative watershed slope of 9.3%.

3.1.5 Soil Conservation Service Curve Number (SCS CN) Estimates:

Many of the nonpoint source pollutant loading models under review in this study utilize the Soil Conservation Service (SCS) Runoff Curve Number (CN) to simulate the runoff from a specified watershed. The final form of the SCS runoff equation is:

$$Q = (P - 0.2S)2/(P + 0.8S)$$

where

Q = runoff (in)
P = rainfall (in)
S = potential maximum retention after runoff begins (in)

S is related to the soil and cover conditions of the watershed through the CN. CN has a range of 0 to 100, and S is related to CN by:

$$S = 1000/CN - 10.$$

The major factors that determine CN are the hydrologic soil group (either A, B, C, or D); cover type (vegetation, bare soil, impervious surfaces); existent treatment or management practices; relative hydrologic condition (good, fair, poor), and antecedent runoff condition. Another factor considered is whether impervious areas outlet directly to the drainage system (hydraulically connected) or whether the flow spreads over pervious areas before entering the drainage system (not hydraulically connected) (SCS, 1986).

Soils maps were acquired from the College of the Atlantic in which the individual soils types were denoted by Field Symbols (COA, 1990). These Field Symbols were then converted into their associated publication symbols using the SCS document, Soil Correlation of Hancock County Area, Maine (LaFlamme, 1987). Finally, the Publication Symbols were used to determine the hydrologic soil groups via the SCS document, Interim-Soil Ratings for Determining Water Pollution Risk for Pesticides--Hancock County Area, Maine (SCS, 1989). Tables 3-3 and 3-4 were then used to select the appropriate SCS Runoff Curve Numbers.

The Old Mill Brook Watershed is comprised of several different soils types which are categorized into various hydrological soils groups. Also, this basin consists of some residential areas in addition to the rural areas. Land use in this watershed also varies. Since no land use maps were available, cover type was determined using field reconnaissance in conjunction with aerial photographs provided by the town of Bar Harbor. CNs were determined for each of the five land uses existing within the Old Mill Brook watershed. The CNs of each land use and the associated area are shown in Table 3-5. The final "composite" curve number is an area-weighted average of the different curve numbers associated with the land uses within the watershed. Tables 3-3 and 3-4 were used to obtain the component curve numbers.

The Upper Hadlock Brook Watershed is comprised of three different soils types, two of which are categorized as hydrological soils group "D." The other is classified as hydrologic soil group "C". Since this basin is a pristine and heavily forested area, the cover type is considered "woods" and the hydrologic condition is

Table 3-3. Runoff Curve Numbers for Urban Areas (from SCS, 1986).

Cover description		Curve numbers for hydrologic soil group—			
Cover type and hydrologic condition	Average percent impervious area[2]	A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.)[3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only)[4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation)[5]		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in table 2-2c).					

---

[1] Average runoff condition, and $I_a = 0.2S$.

[2] The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.

[3] CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.

[4] Composite CN's for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.

[5] Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4, based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

Table 3-4. Runoff Curve Numbers for Rural Areas (from SCS, 1986).

Cover description		Curve numbers for hydrologic soil group—			
Cover type	Hydrologic condition	A	B	C	D
Pasture, grassland, or range—continuous forage for grazing.[2]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow—continuous grass, protected from grazing and generally mowed for hay.	—	30	58	71	78
Brush—brush-weed-grass mixture with brush the major element.[3]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	[4]30	48	65	73
Woods—grass combination (orchard or tree farm).[5]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods.[6]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	[4]30	55	70	77
Farmsteads—buildings, lanes, driveways, and surrounding lots.	—	59	74	82	86

[1] Average runoff condition, and $I_a = 0.2S$.

[2] *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.

[3] *Poor:* <50% ground cover.
Fair: 50 to 75% ground cover.
Good: >75% ground cover.

[4] Actual curve number is less than 30; use CN = 30 for runoff computations.

[5] CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN's for woods and pasture.

[6] *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 3-5. Old Mill Brook Watershed Land Use Areas and Curve Numbers

Land Use	Curve Number	Area (acres)
Farmlands	84	54.1
Residential	80	35.6
Industry	93	1.42
Forest	77	1570.9
Streets - Paved	93	0.95
Streets - Dirt	91	1.05
Watershed	77	1663.9

considered "good." In Table 3-4, the curve number which satisfies the aforementioned criteria for hydrologic soil group "D" is CN = 77, and for hydrologic soil group "C" is CN = 70. Therefore, from the known areas of the different hydrologic soils groups, a composite curve number value was determined to be CN = 76.

The Marshall Brook Watershed, like the Old Mill Brook Watershed, is comprised of both rural and urban areas and calculation of an appropriate CN number follows the procedure of Old Mill Brook Watershed. Since neither land use maps nor aerial photographs were available for this watershed, it became difficult to determine any information concerning the different cover types. Field reconnaissance did provide some information, but accurate measures of the areas of the specified cover types could not be determined from the field. Therefore, curve numbers were not determined for this watershed. Table 3-6. summarizes the physical characteristics of the sampling stations.

3.2 Hydrology

The monitoring program included determination of stream flow and stage height at the six stations. For the sake of completeness, the following brief narrative is offered on the technique used. The velocity-area method used in the monitoring of stream flow was in accordance with the ASTM method (ASTM, 1980). Since the principle of this method is based on effectively and accurately measuring the flow velocity and cross-sectional area, it is

Table 3-6. Primary Sampling Station and Watershed Data Summary

Sampling Station	Station Latitude (d/m/s)	Station Longitude (d/m/s)	Station Elevation (feet)	Watershed Slope (%)	Watershed Area (acres)	SCS Curve Number
1. Hadlock Brook	44/19/29	68/17/06	258.0	14.4	398.1	76
4. Old Mill Brook	44/24/51	68/17/47	19.7	4.1	1663.9	77
5. Marshall Brook	44/17/03	68/20/50	60.0	9.3	1065.6	81

d/m/s = degrees/minutes/seconds

important that the channel cross-section selected for velocity measurements be stable and free from physical obstruction (Runge, 1989).

All of the sampled streams were less than 2.5 feet deep. Hence, stream velocity was measured at the recommended six-tenths method, i.e., at a point in the vertical equivalent to six-tenths below the water surface. This was performed at 0.5 foot to 1 foot intervals along the horizontal, depending on the width of the stream in order to obtain at least 15 readings. A low-flow, digital current meter, model 201D manufactured by Marsh-McBirney, Inc., (Gaithersburg, MD) was used to measure the stream flow. The meter is based on the electromagnetic field principle utilizing Faraday's Law.

Measuring flow in a stream is a tedious and time consuming task. To provide a more convenient and less time consuming method, the water surface elevation at a point along the stream, or stage, can be related to the flow, creating a flow-stage discharge relationship. Permanent stage markings were established at one location along the stream in each of the three watersheds. A 5/8 inch metal rod was pounded into the ground, the top of which acted as the permanent mark from which distance to the water surface was measured. With sufficient measurement of stream flows and corresponding stage readings at various flows, a stage-discharge rating curve can be derived for each of the stations. These rating curves will enable one to estimate flows in the future by measuring only the stage. It is hoped that this may provide data for future use. Due to the limited gaging performed to date, no rating curves could be constructed yet. All hydrology data collected to date are summarized in Appendices M.

3.3 Water Quality Monitoring

As previously mentioned, water quality monitoring was performed one time for several selected constituents to determine "ballpark" current conditions. Samples were collected in various sized polyethelene bottles, preserved as required for the particular constituent, and placed on ice. Samples were analyzed at the URI Civil and Environmental Engineering Laboratories in Kingston, RI. This resulted in sample storage times of approximately 4 days. Appendix M summarizes water quality data collected.

3.4 Precipitation Data

In order to estimate the average runoff which occurs in the Mt. Desert Island region for any given period of time, it was necessary to obtain localized precipitation data. All watershed loading models are driven by precipitation data. The runoff estimations calculated from rain data can be used to determine pollutant export mass loadings by using mass balance calculations.

The National Weather Service (NWS) has one official raingage located on Mount Desert Island; the Acadia National Park station (Station No. 1700-01300-3) located at McFarland Hill in Hancock County, Maine (44° 21' Latitude, 68° 16'W Longitude, 470 ft elevation). Figure 3-4 indicates the location, which is at the Park Headquarters Building. The inception date of the Acadia National Park rain gauge station was September 1982, hence the record is fairly short. As with most NWS raingages, hourly data is available. A summary of the annual precipitation data appears in Table 3-7.

The previous studies of the Upper Hadlock Brook Watershed include precipitation data collected within the watershed boundaries (Heath, 1990). Comparisons of monthly precipitation depths during periods when the tipping bucket recorder within the Hadlock Pond watershed (HPWS) was operational show a nearly 1:1 correspondence with the precipitation depth data generated at the Acadia National Park site (Heath, 1990).

3.5 Land use Data:

These data include the land areas devoted to the various land use classification types. Examples include residential development (broken into several density categories and especially areas with individual sewage disposal systems), cropland, turf farming, orchards, livestock, commercial and industrial areas, landfill sites, roadway areas, forested areas (broken into general tree types), and so on.

Accurate land use data is crucial because one of the prime directives of this study involves the evaluation of the impacts which surrounding land use has on the watershed's water resources. In addition, model capability will be demonstrated through changing land use types and evaluating the model's response.

Since current land use maps were not available at the time of this study, aerial photographs were utilized as an alternate means of addressing the apparent lack of land use data. The most recent set of aerial photographs of the Mount Desert Island region were taken in 1987. These area in black and white and in several different scales. Subsequently, estimates of the current land use status of

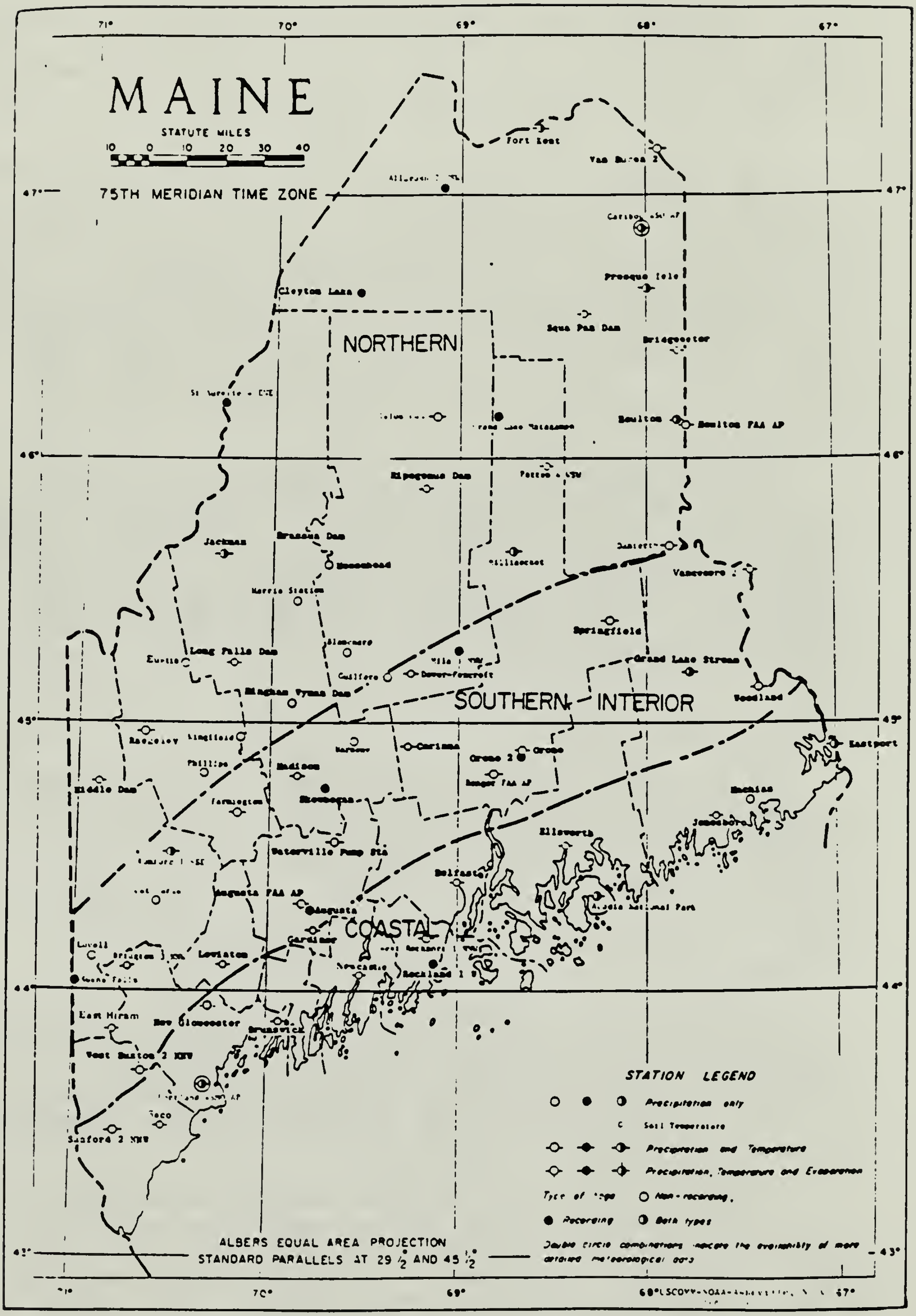

Figure 3-4. Location map of Acadia National Park precipitation station.

Table 3-7. Annual Precipitation Data for Acadia National Park.

Year	Annual Precipitation (inches)
1982	incomplete
1983 w	76.20 E
1984	50.60 *
1985	47.79 E
1986	59.10
1987 d	46.22 *
1988 a	55.85 E
1989	54.80 *
1990	incomplete
1991	incomplete

E = Total precipitation estimated by NOAA (indicates that the precipitation for one or more months was estimated for this gauging station).

* = Total precipitation estimated by URI (indicates that data is missing for all or part of the period and no estimation by NOAA was made)

w = wet year d = dry year a = average year the Island were provided by the aerial photographs available from the town offices of Bar Harbor and Southwest Harbor. A much more comprehensive and detailed data set is currently being compiled by Kurt Jacobson and John Anderson of the College of the Atlantic (COA), where work is being performed to complete a digitized land use data base.

3.6 GIS Data

As is evident throughout this report, an extensive amount of input data is required in the application of hydrologic simulation models. This is particularly true of empirically based models which attempt to simulate each component of the precipitation runoff process. Often the effort required to collect the appropriate data discourages the use of these computer simulation models. Geographic Information Systems (GIS) are a rapidly evolving technology which can efficiently store, retrieve, manipulate, analyze, and display spatial data (Chase, 1991). GIS also has powerful mapping capabilities. Numerous data bases are being prepared in many technical and nontechnical areas using GIS. These include information such as watershed areas, landuse types, zoning, soil types, demographics, roadway mileage, and so on.

In addition to facilitating input data requirements, GIS can be used as a post processor of model output. For example, model output for several parameters can be compared and displayed simultaneously to provide a multitude of visual indicators. Overlay capabilities allow for the generation of new maps using several existing data sets.

3.6.1 GIS Data Availability

The NPS's official GIS is GRASS. Currently, the College of the Atlantic (COA) in Bar Harbor, ME is completing a digitized data set using the ArcInfo GIS system. Due to the proximity of COA, Acadia National Park will be using ArcInfo. The ArcInfo package processes data in a vector format while the GRASS package is a rasterized (cell-based) system. The information provided by the COA could prove invaluable to further studies involving the development of a GIS interface with the chosen simulation model. Once a GIS interface is established, input parameters could be drawn directly from the GIS database, greatly facilitating application to different watersheds owned by the National Park Service on Mount Desert Island and elsewhere.

An effective GIS/nonpoint source model interface could be in the form of an external computer program which would select appropriate data from the GIS data base, manipulate the data, and create an input file in a format compatible with the nonpoint source model. The nonpoint source model would then be run separately using the GIS created input file. An interface of this type has been developed for the Stormwater Management Model (SWMM) and has been indicated to perform well (Chase, 1991).

In accordance with the fourth objective set forth by the National Park Service (Section 1.3), the Nonpoint Source pollution models reviewed for use in this study were evaluated as to their interface capabilities with the GIS system. Of all the models reviewed, two are currently being modified to incorporate the capability for direct data entry via a GIS package.

CHAPTER 4
MODEL APPLICABILITY TO ACADIA NATIONAL PARK

The passage of the Federal Water Pollution Control Act (popularly known as the Clean Water Act), PL 92-500, by the U.S. Congress in 1972 resulted in the need for mathematical models to evaluate nonpoint source pollution from a variety of different land uses. This need produced a proliferation of model development (Leonard and Knisel, 1986). Many of the models developed early on are now considered obsolete and thus are not considered for application to this particular study. There are, however, quite a large number of nonpoint source pollution models in use today.

These computer-aided models that simulate the movement of constituents and particulates from their source to surface waters have been recognized as tools to evaluate the causes and consequences of pollutants in water and to assist decision makers in wiser water resource planning. In order for many of these models to act as viable management tools, they must be rigorously tested and calibrated to the local conditions in which they are to be employed. The first step, however, must be to determine if a given simulation model is useful to and usable by those persons for which the model is designed (Bill and Bartholic, 1988). Thus, the burden is upon the model user to select from several potential models the one(s) which will best represent the conditions, practices, and desired results for the specific problem (Leonard and Knisel, 1986).

The National Park Service is interested in a model capable of serving as a mechanism for identifying stressed park ecosystems due to urbanization, as well as allowing park planners to foresee, and hopefully avoid, adverse future water quality impacts. Since the interest is in the long term effects that land use changes will have on receiving water quality, one of the criteria for model selection is the capacity for continuous simulation. Furthermore, the selected model must be able to differentiate between different land use types in some capacity to facilitate its usefulness to the park planners.

It is conceivable that the park planners will confront the model with several planning scenarios in order to evaluate the best management strategies. Therefore, a user friendly, interactive model would be desirable.

Another factor which will govern the evaluation process involves the need for the model to be geared toward rural applications. Using these criteria, each model is evaluated as to its applicability to Acadia National Park. A model used properly should provide park managers with the ability to make recommendations regarding land use practices within the bounds of the park and outside the parks boundaries if the suspected areas (watersheds) are adequately described by the model.

It is important to note that all of the models reviewed for this study have been applied to watersheds by the model developers as a means of testing the accuracy of simulation. In some instances, the models have been chosen for application to watersheds by persons not directly involved in the model development. The documentation of these applications to several different watershed scenarios provides the most comprehendible and most accurate assessment of the model's usefulness and capabilities. The following sections discuss the findings of some of the previous studies involving the seven models reviewed for this project.

Research was performed to acquire fundamental information about as many models as possible. Models which obviously did not satisfy the objectives of this study were discarded completely during this initial phase. These included models which are extremely complex and geared toward a comprehensive study of the intricate mechanisms of pollutant generation and transport within a watershed. Other models which showed some initial promise were brought to the next phase in which they underwent a comprehensive review. Six models were reviewed in detail: HSPF, AGNPS, ANSWERS, CREAMS, NPS, and GWLF. In the appendix, the preliminary evaluations describe the physical characteristics of each model. In the following sections, each model will be reviewed as to its applicability to Acadia National Park, Maine.

4.1 Hydrological Simulation Program - FORTRAN (HSPF):

HSPF is the most comprehensive model that was considered for this study. The model is capable of simulating all processes of interest for this study. HSPF was eliminated as a potential candidate for this project, however. HSPF requires very detailed data input to perform its simulations. The model is not user-friendly, and due to its extremely complex nature it could pose difficulties to park planners who may have to make modifications in the input structure to simulate land use changes. HSPF is a large model that requires a considerable effort in input data preparation and needs abundant computer resources.

The data needed to properly calibrate and validate the HSPF model far exceeds the scope of this project. For a discussion and description of the HSPF model mechanics, please refer to Appendix A.

4.2 Agricultural Nonpoint Source Model (AGNPS):

AGNPS is one of two finalists that have been chosen as possible candidates for application to the three selected watersheds on Mount Desert Island, Maine. The model inputs are readily available from site investigation and reference materials. AGNPS simulates runoff, sediment and nutrients, but does not model the transport of trace metals. The model is equipped with a user-friendly shell, on-line help, and an easy to use spreadsheet format for editing data input. All options within the edit mode are accessible by mouse or cursor.

According to the model developers (Young et al., 1989), the AGNPS model has been preliminarily tested for runoff estimations with data from 20 different watersheds located in the north central United States, with very close agreement. Parts of the model also have been tested primarily for sediment yield estimates with data from two experimental watersheds near Treynor, Iowa, and another near Hastings Nebraska. Sediment yield estimates from the model compared favorably with the measured values from the three watersheds.

AGNPS was successfully applied to the Garvin Brook Watershed and the Salmonson Creek Watershed in southern Minnesota (Young et al., 1989). The watersheds are hilly with forest and agriculture as the dominant land use types. Output from the AGNPS model was used to pinpoint critical areas within the watersheds.

AGNPS (Young et al., 1987) was applied to the Little Swan Creek Watershed in Branch County, Michigan and a sensitivity analysis was conducted to determine which input parameters affected the model outputs (Bill and Bartholic, 1988). Evans and Miller (1988) evaluated an integrated GIS/simulation modeling approach with AGNPS to assess agricultural nonpoint source pollution problems within the Mahantango Creek watershed in Central Pennsylvania. The GIS package utilized in the Pennsylvania study was the grid cell based system known as ERDAS (Earth Resources Data Analysis System). Evans and Miller determined that a GIS interface could decrease the expenses of creating an input data file for the AGNPS model by 50% when compared to typical consulting rates.

AGNPS is a distributed parameter model which provides the model with certain attractive features. With distributed parameter models, changes in the watershed and their effect on the output can be modeled easily and more effectively (Novotny, 1986). Often, "where" changes are taking place is just as significant as "what" changes are taking place, within a given watershed area. Distributed parameter models, such as AGNPS, are intrinsically able to model these spatial effects, and monitor their impact as they propagate towards the watershed outfall.

Because of its cell-based structure, AGNPS can describe the watershed in such a detailed manner that it is claimed to be initially very accurate, and thus reduces the comprehensive calibration effort commonly associated with lumped parameter models. The model has provision for "fine tuning", however, if calibration data is available.

The principal problem with AGNPS involves its temporal capabilities. AGNPS is a single storm event model which means that until modifications are made, continuous simulation will not be possible. In the case of this watershed study, continuous simulation would be more meaningful than event simulation since the scope of the project explicitly states that the National Park Service is interested in the long term effects of land development. Another drawback with AGNPS is that the model does not have the capability to simulate the transport of trace metals. Although trace metal simulation is not a requirement for model selection, it is a desirable feature. For a discussion and description of the AGNPS model mechanics, refer to Appendix B.

4.3 Areal Nonpoint Source Watershed Environmental Response Simulation (ANSWERS):

Answers is a distributed parameter model which simulates watershed processes on an event time scale. As explained earlier, continuous simulation is desirable when considering the long term impacts of diffuse pollution. In addition, ANSWERS considers sediment and erosion control primarily. The version of ANSWERS that was reviewed for this study considered no other water quality constituents, although versions expected to be released soon will make some other chemical predictions.

The ANSWERS model (Beasely, 1977; Beasely et al., 1980; Beasely and Huggins, 1982) was applied to the Finley Creek Watershed in Indiana. The watershed has a rolling topography and is agricultural (Beasely, 1986). In addition, the model was applied to a construction site within the Eagle Creek watershed in Indiana (Beasely, 1986). For a discussion and description of the ANSWERS model mechanics, refer to Appendix C.

4.4 Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS):

CREAMS was designed for application to small, field-sized agricultural areas of less than 100 acres. This assumption immediately eliminates the model as a possible candidate because each of the three selected watersheds have areas of greater than 100 acres.

The CREAMS model (Knisel, 1980) has been tested with data from research watersheds in several land resource areas with various conclusions. After comparing annual runoff from 46 sites in the southern and midwestern U.S. to predict values, Smith and Williams (1980) concluded that the hydrology submodel was satisfactory. But less satisfactory runoff predictions were observed in the United Kingdom (Morgan and Morgan, 1982) and Georgia (Lane and Ferreira, 1980). Tests of that erosion/sedimentation model have resulted in satisfactory results in the Midwest (Foster and Ferreira, 1981) and the United Kingdom (Morgan and Morgan, 1982). However, both sediment yield and phosphorus exports were underpredicted in Georgia (Lane and Ferreira, 1980) (Jamieson and Clausen, 1988).

Morgan (1985) successfully predicted long-term annual soil erosion in the United Kingdom using CREAMS. However, he found that CREAMS gave very poor predictions of runoff on a daily or monthly basis. Pathak et al. (1984) found CREAMS to underestimate runoff during months of the cool season and overestimate runoff during the months of the warm season for the grasslands of Oklahoma. Bengston and Carter (1985) applied CREAMS for flat lands of the lower Mississippi Valley and found that it underestimated the monthly runoff in the cool season by 38% while overestimating runoff in the warm season by 61% (Ewing, 1989). For a discussion and description of the CREAMS model mechanics, refer to Appendix D.

4.5 Nonpoint Source Model (NPS):

NPS is currently incorporated in the HSPF model and is no longer available as a separate entity. Refer to section 5.1 for a discussion of the model's applicability to this study. For a discussion and description of the NPS model mechanics, refer to Appendix E.

4.6 Generalized Watershed Loading Functions (GWLF):

GWLF is the other finalist chosen for application to Acadia National Park study. GWLF is equipped with a user friendly shell, on line help, and an easy to use editing system which is designed to facilitate the modification of input data to simulate changes in land use. The model inputs are readily available from site investigation and reference materials, many of which are provided in the user's manual. In addition, the model provides default parameters for baseline nutrients data in the event that actual data is not available for the watershed being modeled. GWLF simulates runoff, sediment and nutrients, but does not model the transport of trace metals.

The GWLF model (Haith and Shoemaker, 1987; Wu et al., 1987) was tested by comparing model predictions with measured stream flow, sediment, and nutrient fluxes from the West Branch Delaware River Basin during a three-year period (April 1979 to March 1982) (Haith and Shoemaker, 1987). The study demonstrated that the GWLF predictions were in good agreement with measured values.

GWLF was also applied to the tidal, freshwater Hudson River estuary to examine the controls on inputs of organic carbon and sediment to the estuary (Howarth et al., 1991). The model was found to be a "useful tool" in exploring the nonpoint source inputs to the estuary.

The GWLF model considers dissolved and solid phase nitrogen and phosphorus from point sources, ground water, and rural runoff sources. Rural loads are transported in runoff and eroded soils. Dissolved loads are the product of runoff and dissolved concentrations. Runoff and erosion are computed by the Universal Soil Loss Equation. Solid phase nutrient loads from rural areas are given by the product of monthly sediment yield and average sediment nutrient concentrations. Sediment yield is the product of erosion and sediment delivery ratio. Urban nutrient loads are modeled by exponential washoff functions. Nutrient accumulations are assumed constant and are a function of land use. Daily evapotranspiration is calculated as the product of an area cover coefficient and potential evapotranspiration. The model estimates the potential evapotranspiration from daylight hours, saturated water vapor, and daily temperature.

GWLF considers both surface and groundwater discharge. Groundwater is estimated from a lumped parameter watershed water balance. Daily water balances are calculated for both saturated and unsaturated layers. Infiltration is calculated as any excess resulting from rainfall and snow melt less runoff and evapotranspiration.

The saturated zone is modeled as a simple linear ground water reservoir.

GWLF is a lumped parameter model in essence, in that it does not follow the traditional cell format. The model does, however, have some distributive features. Instead of dividing the watershed into arbitrary geometrical components (cells), GWLF divides the watershed into different land use types. The model cannot provide the spatial analysis that traditional distributive parameter models provide, but GWLF does output the mass loadings of sediment and nutrients contributed by each land use present in the watershed. This feature is of particular interest when considering the objectives of the project because the model will not only simulate the effects of land use changes at the watershed outfall, but it will also describe what pollutants the new land use is contributing separately.

GWLF is designed to provide continuous simulation of watershed processes, and output is given in monthly or annual intervals. Thus, GWLF is well suited for providing park planners with information about the long term impacts of proposed developments or other land use changes.

GWLF is currently undergoing computer code revision. A new version is expected late in 1992 which will incorporate nutrients loads from onsite wastewater systems (septic tanks, leaching fields). Also, conjunctive uses of GWLF and GIS are being explored. The general approach is to use GIS to aggregate the land use and soils information which is then processed by a data base type program to produce actual GWLF input files. The two programs are anticipated to be run independently. For a discussion and description of the current GWLF model mechanics, refer to Appendix F.

As discussed, two finalists emerged from this review; AGNPS and GWLF. Due chiefly to the inability of AGNPS to simulate a watershed in a continuous, long term fashion, GWLF was chosen as the most viable model at this point. The application of GWLF is presented in Chapter 5.

CHAPTER 5
APPLICATION OF THE GENERALIZED WATERSHED LOADING FUNCTIONS (GWLF) TO SELECTED WATERSHEDS ON MOUNT DESERT ISLAND, MAINE

The Generalized Watershed Loading Functions (GWLF) model was selected as the tool which best satisfied the needs of the National Park Service, as discussed in Chapter 4. In order to apply a model to a given watershed, a relatively large amount of data is required to satisfy the model input data structure. A modeling effort, therefore, is only as accurate as the data used to drive the model.

In this study, data availability was somewhat of a problem. Nevertheless, the greatest effort was put forth to apply the GWLF model to the selected watersheds with whatever data was found. Unfortunately, due to a lack of current land use data for Mount Desert Island, the GWLF model was not applied to the Marshall Brook watershed. Because the Hadlock Brook Watershed consists entirely of woodlands, the lack of land use data did not effect the model application to that watershed. In the case of Old Mill Brook Watershed, aerial photographs were obtained from the Town of Southwest Harbor and used in lieu of land use records. It is anticipated that an inventory of land use data in a GIS package may provide the crucial link to this important piece of information.

5.1 Parameter Derivation

The following section discusses the input parameters required by the GWLF model, and provides procedures used to derive these inputs for the model application to the Hadlock Brook and Old Mill Brook Watersheds. As described in Appendix G, GWLF accepts three input data files. Appendix N consists of a copy of the GWLF User's Manual, which is referred to directly in this discussion for its graphs, figures and reference tables. As will be observed, GWLF has provision for SI (metric) units only. This may be somewhat of a disadvantage since the engineering profession in this country is dominated by English units.

Required weather data (**WEATHER.DAT**) include daily temperature (°C) and precipitation (cm) records for the simulation period. Transport parameters (**TRANSPRT.DAT**) are the necessary hydrologic, erosion/sediment and land use data for the various rural and urban runoff sources.

Nutrient parameters (**NUTRIENT.DAT**) include the various nitrogen and phosphorus data required for loading calculations (Wu et al.,1989).

GWLF requires the **WEATHER.DAT** and **TRANSPRT.DAT** data files to run, and is capable of accepting the third file if nutrient loads are to be predicted. Tables 5-1 and 5-3 are the text versions of the **TRANSPRT.DAT** and **NUTRIENT.DAT** input data files for the Hadlock Brook Watershed, respectively. Similarly, Tables 5-2 and 5-4 show the input parameters for the GWLF application to the Old Mill Brook Watershed. The input parameters for the Hadlock Brook and Old Mill Brook watersheds were derived using the same sources. The following sections summarize the choice of input parameters for the three data files.

WEATHER.DAT

The weather file is arranged such that the first entry of each month is the number of days in the month, and subsequent entries being temperature (°C) and precipitation (cm) for each day (Wu et al., 1989). The precipitation data selected to drive the GWLF model for application to the Hadlock Brook and Old Mill watersheds corresponds to the 'wet year' and 'dry year' precipitation data with respect to the life of the Acadia National Park rain gage. The wet year, adjusted for GWLF's definition of "year" occurred from April 1983 to March 1984, the dry year from April 1987 to March 1988. Hyetographs (precipitation versus time) for the wet and dry years recorded at Acadia National Park Headquarters are shown in Appendix H.

Average Daily Temperature (°C):

Maximum and minimum values of daily temperature were acquired through the National Park Service headquarters on Mount Desert Island. The acquired hourly data were averaged for each day and then converted from °F to °C.

Precipitation (cm):

Precipitation data were acquired from daily totals found in the Hourly Precipitation Data for the New England region. These data were obtained from the National Oceanic and Atmospheric Administration (NOAA) station located in Portland, Maine in inches and were converted to centimeters before serving as input into the data file. These data are also available from the National Climatic Data Center in Asheville, NC.

Table 5-1. GWLF Input: Hydrology and Erosion/Sediment Component for the Hadlock Brook Watershed.

```
TRANSPRT DATA

LAND USE       AREA(ha)         CURVE NO         KLSCP
FOREST            161.           76.0             0.00400

MONTH      ET CV()    DAY HRS    GROW. SEASON     EROS. COEF
APR         0.510      13.2       0                .229
MAY         0.850      14.5       1                .229
JUNE        0.980      15.2       1                .229
JULY        1.000      14.8       1                .229
AUG         1.020      13.7       1                .229
SEPT        1.030      12.3       1                .229
OCT         1.010      10.8       1                .076
NOV         0.500      9.5        0                .076
DEC         0.440      8.8        0                .076
JAN         0.490      9.2        0                .076
FEB         0.510      10.3       0                .076
MAR         0.510      11.7       0                .076

ANTECEDENT RAIN+MELT FOR DAY -1 TO DAY -5
 0          0          0         2.03      0

INITIAL UNSATURATED STORAGE(cm)=    0
INITIAL SATURATED STORAGE(cm)  =    2.7
RECESSION COEFFICIENT          =    .1
SEEPAGE COEFFICIENT            =    0
INITIAL SNOW(cm water)         =    0
SEDIMENT DELIVERY RATIO        =   0.320
```

Table 5-2. GWLF Input: Hydrology and Erosion/Sediment Component for the Old Mill Brook Watershed.

TRANSPRT DATA

LAND USE	AREA(ha)	CURVE NO	KLSCP
FARMLAND	22.	84.0	0.01300
FOREST	636.	77.0	0.00090
INDUSTRIAL	1.	93.0	0.00090
RESIDENTIAL	14.	80.0	0.00100
PAVED ROADS	0.	93.0	0.00090
DIRT ROADS	0.	91.0	0.00090

MONTH	ET CV()	DAY HRS	GROW. SEASON	EROS. COEF
APR	0.510	13.2	0	.229
MAY	0.850	14.5	1	.229
JUNE	0.980	15.2	1	.229
JULY	1.000	14.8	1	.229
AUG	1.020	13.7	1	.229
SEPT	1.030	12.3	1	.229
OCT	1.010	10.8	1	.076
NOV	0.500	9.5	0	.076
DEC	0.440	8.8	0	.076
JAN	0.490	9.2	0	.076
FEB	0.510	10.3	0	.076
MAR	0.510	11.7	0	.076

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

0	0	0	2.03	0

INITIAL UNSATURATED STORAGE(cm) = 0
INITIAL SATURATED STORAGE(cm) = 2.7
RECESSION COEFFICIENT = .1
SEEPAGE COEFFICIENT = 0
INITIAL SNOW(cm water) = 0
SEDIMENT DELIVERY RATIO = 0.240

Table 5-3. GWLF Input: Nutrient Component for the Hadlock Brook Watershed.

```
NUTRIENT DATA

LAND USE              DIS.NITR IN RUNOFF(mg/l)      DIS.PHOS IN RUNOFF(mg/l
FOREST                     .19                           .006

LAND USE              NITR.BUILD-UP(kg/ha-day)      PHOS.BUILD-UP(kg/ha-day

MONTH                 POINT SOURCE NITR.(kg)        POINT SOURCE PHOS.(kg)
APR                         0                             0
MAY                         0                             0
JUNE                        0                             0
JULY                        0                             0
AUG                         0                             0
SEPT                        0                             0
OCT                         0                             0
NOV                         0                             0
DEC                         0                             0
JAN                         0                             0
FEB                         0                             0
MAR                         0                             0

NITROGEN IN GROUNDWATER(mg/l):        0.190
PHOSPHORUS IN GROUNDWATER(mg/l):      0.006
NITROGEN IN SEDIMENT(mg/kg):         500
PHOSPHORUS IN SEDIMENT(mg/kg):       500
```

Table 5-4. GWLF Input: Nutrient Component for the Old Mill Brook Watershed.

```
NUTRIENT DATA

LAND USE             DIS.NITR IN RUNOFF(mg/l)      DIS.PHOS IN RUNOFF(mg/l
FARMLAND                   3                             .25
FOREST                     .19                           .006

LAND USE             NITR.BUILD-UP(kg/ha-day)      PHOS.BUILD-UP(kg/ha-day
INDUSTRIAL                 .234                          .011
RESIDENTIAL                .008                          .0015
PAVED ROADS                .234                          .011
DIRT ROADS                 .234                          .011

MONTH                POINT SOURCE NITR.(kg)        POINT SOURCE PHOS.(kg)
APR                        0                             0
MAY                        0                             0
JUNE                       0                             0
JULY                       0                             0
AUG                        0                             0
SEPT                       0                             0
OCT                        0                             0
NOV                        0                             0
DEC                        0                             0
JAN                        0                             0
FEB                        0                             0
MAR                        0                             0

NITROGEN IN GROUNDWATER(mg/l):       0.340
PHOSPHORUS IN GROUNDWATER(mg/l):     0.013
NITROGEN IN SEDIMENT(mg/kg):        1000
PHOSPHORUS IN SEDIMENT(mg/kg):      1000
```

TRANSPRT.DAT

Land Use:

Since land use maps of Mount Desert Island were unavailable for this study, land use determinations were based on aerial photographs in conjunction with on-site inspection. The Hadlock Brook watershed was found to contain only "forest" as an individual land use type, whereas the Old Mill Brook watershed contained six land use classifications.

Area (ha):

Once the individual land uses within the watershed were determined from the aerial photographs and site investigation, the land uses were superimposed on the soils map for that watershed which was acquired through the College of the Atlantic. Determination of the individual land use area was accomplished by a planimetering process, using a Tamaya digital planimeter model Planix 5. For the Hadlock Brook watershed the area of the single land use was determined to be 398.1 acres, which corresponds to 161 ha. The areas of the six individual land uses of the Old Mill Brook watershed were determined using the same methodology.

Curve Number:

Composite curve numbers were determined for each land use using the soils maps. The Upper Hadlock Brook Watershed is comprised of 398.1 acres consisting of three different soils types, two of which are categorized as hydrological soils group "D." The other is classified as hydrologic soil group "C". Since this basin is a pristine and heavily forested area, the cover type is considered "woods" and the hydrologic condition is considered "good." In Table 3-4, the curve number which satisfies the aforementioned criteria for hydrologic soil group "D" is CN = 77, and for hydrologic soil group "C" is CN = 70. The area of the watershed comprised of hydrologic soil group "D" is 368.2 acres and the remaining 29.8 acres is made up of hydrologic soil group "C". The composite curve number is:

$$CN = \frac{(368.2)(77) + (29.8)(70)}{398.1} = 76.$$

Therefore, from the known areas of the different hydrologic soils groups, a composite curve number value was determined to be CN = 76 for the Hadlock Brook Watershed. The composite curve numbers for the six individual land uses within the Old Mill Watershed were determined using the same procedure.

KLSCP:

The Universal Soil Loss factors K, LS, C and P form the erosion input parameter KLSCP, where:

K = Soil Erodibility Factor: This factor was determined for each soils type via the Soil Conservation Service in Orono, Maine (LaFlamme, 1987; SCS, 1989; SCS, 1987) and an area weighted average is computed for each land use. For the Hadlock Brook watershed $K_{total} = 0.17$.

LS = Slope length factor: This factor was determined for each watershed by the equation which is valid for slopes exceeding 4 percent

$$LS = (L)^{0.5} (0.0138 + 0.00974S + 0.00138S^2)$$

where L = length from point of origin to end of slope (m)

S = average slope (%)

The slopes of the three selected watersheds were determined in section 3.1.4.

For the Hadlock Brook Watershed, L = 2408 m and S = 14.4 %, therefore

$$LS = 21.6$$

C = Cropping and management factor: This factor was determined using published sources (SCS, 1975b). The value of C used for the Hadlock Brook watershed corresponds with managed woodland with a tree canopy of 75-100% was C = 0.001.

P = Conservation practice: The value of the conservation parameter was assumed to equal unity because no conservation practices are being used in the watersheds selected for this study.

Therefore, for the Hadlock Brook Watershed, the KLSCP factor is $KLSCP = (0.17)(21.6)(0.001)(1) = 0.0036 \approx 0.004$. The KLSCP values were determined for each land use in the Old Mill Brook Watershed using the same procedure.

Arrangement of "Weather Years" (months):

This input should coincide with the weather data which "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 the watershed unsaturated zone is at field capacity and runoff events have 'flushed' the watershed of the previous year's accumulated sediment. In the eastern U.S. this generally occurs in the late spring and hence in such locations an April - March weather year is appropriate" (Wu et al., 1989).

Evapotranspiration cover coefficient:

This parameter is used in the groundwater water budget model in the calculation of evapotranspiration. The values of this parameter are inputted for each month and are available from published references (U.S. Forest Service, 1980).

Average Daylight Hours:

This parameter is used in the groundwater water budget model in the calculation of evapotranspiration. The mean daylight hours per day was inputted for each month for the Mount Desert Island region as a function of latitude (Mills et al., 1985).

Growing Season Flag (0,1):

"Growing (1) and dormant (0) seasons are designated based on mean daily air temperature, with dormant months being those with mean temperatures below 10°C." This parameter is used to calculate the recommended values (Ogrosky & Mockus, 1964) for the break points in the curve number values for antecedent moisture conditions 1 (driest), 2 (average) and 3 (wettest) (Wu et al., 1989).

Erosion coefficient:

This parameter, the seasonal rainfall erosivity coefficient "a" for the Richardson et al. (1983) rainfall erosivity relationship, is used for the generation of solid phase sediment and erosion from rural land uses within the model. Values of this parameter from Portland, Maine were chosen to be representative of the Mount Desert Island region (Selker et al., 1990).

Antecedent Rain+Melt for Day -1 to Day -5:

These five inputs are taken directly from the precipitation data collected for the construction of the

WEATHER.DAT data file. In the case of the April - March weather years, the antecedent rain and melt for day -1 to day -5 would correspond to the precipitation (cm) occurring during each of the last five days of the month of March for the year preceding the initial year of the chosen simulation. For example, if the simulation period extended from April 1987 to March 1988, then antecedent rain and melt for day -1 to day -5 would be the precipitation that occurred during the last five days of March 1987.

These parameters are used in the calculation of the actual curve number for a specific day, which is selected as a linear function of the 5 - day antecedent precipitation (Wu et al., 1989).

Initial Unsaturated Storage (cm):

This parameter is a required input to the groundwater portion of the model. The initial unsaturated storage refers to the amount of water (moisture level in centimeters) which is contained within the unsaturated zone of the watershed at the initial instant of simulation. Figure 5-1 illustrates the lumped parameter concept utilized in the groundwater portion of the model. Since the simulation year starts at a time when the watershed is wet (April), the initial unsaturated storage parameter can be normalized to zero (Wu et al., 1989).

Initial Saturated Storage (cm):

This parameter represents the moisture level which occupies the saturated zone at the beginning of simulation. This parameter can be estimated using the estimated value of the recession constant in conjunction with baseflow data (measured streamflow data at times of low flow). In accordance with the GWLF User's Manual and estimated baseflows, a value of 2.7 cm was selected for this study. This is within the range suggested by the GWLF user's manual. A sensitivity analysis described later will assess the importance of this parameter.

Recession Constant:

The recession constant (r) is an important parameter in the ground water/hydrologic budget portion of the GWLF model. The recession constant is the decay coefficient used by the model when predicting the shallow saturated zone moisture level at various times throughout the duration of simulation. Figure 5-1. shows the shallow saturated zone as the source of groundwater discharge to the stream. The recession constant also governs how much of the moisture within the saturated zone is discharged via groundwater to the stream.

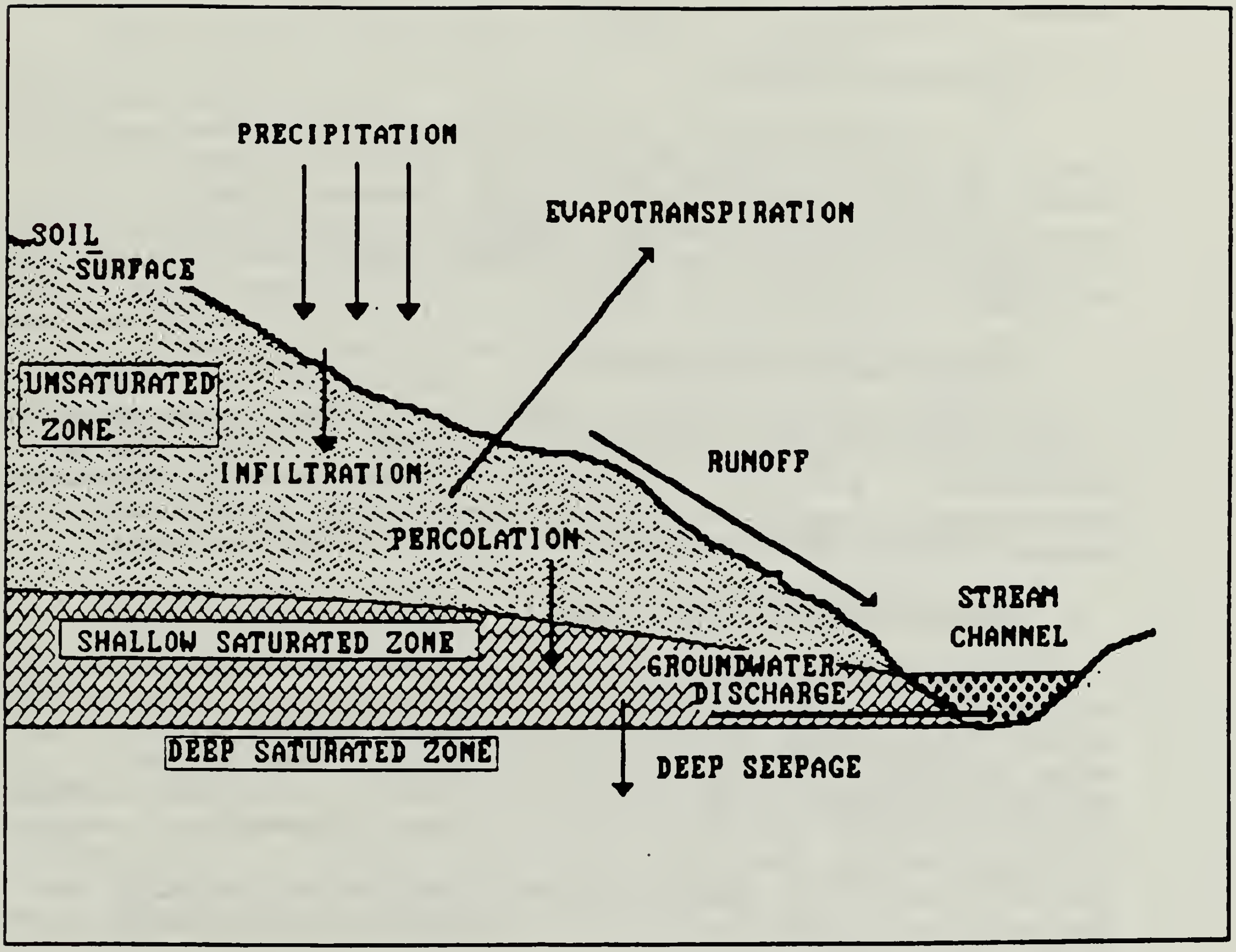

Figure 5-1. The GWLF lumped parameter model indicating groundwater discharge (from Wu et al., 1989).

Estimates of the recession constant r can be estimated from streamflow records by standard hydrograph separation techniques (Chow, 1964). Recession constants are measured for a number of hydrographs and an average value is used for the simulations (Wu et al., 1989). A recession constant value of r = 0.1 was chosen as a realistic value with which to generate output from the GWLF model. Future modeling efforts will require several measured hydrographs in order to accurately estimate the recession constant parameter.

Seepage Constant:

No standard techniques are available for estimating the rate constant for seepage loss (s). The most conservative approach is to assume that s = 0 (all precipitation exits the watershed in evaporation or streamflow). Otherwise the constant must be determined by calibration (Wu et al., 1989).

Initial snow (cm water):

This input is simply the value for amount of snow (cm water) that is present on the ground on the first day of simulation. A value of zero was entered for this input parameter because there was no snow at the commencement of simulation in April of 1983.

Sediment Delivery Ratio:

The value of this input parameter, the watershed delivery ratio, was read from a graph (Vanoni, 1975) which gives the sediment delivery ratio as a function of drainage area (square kilometers), provided in the GWLF User's Manual (appendix N) as Figure B-1 (Wu et al., 1989). This input parameter is used in the erosion and sediment portion of the model to determine the total sediment yield, which is the product of erosion (determined using the KLSCP and the erosion coefficient input parameters) and the sediment delivery ratio.

For the Hadlock Brook watershed, the value of the sediment delivery ratio was determined from the watershed drainage area of 398 acres (1.61 square kilometers) to be 0.32. For the Old Mill Brook watershed, a sediment delivery ratio of 0.24 was determined from the graph using the total watershed drainage area of 6.73 square kilometers.

NUTRIENT.DAT

A set of default parameters which are average values obtained from published water pollution monitoring studies have been developed to facilitate uncalibrated applications. The sources of these studies are given and the values of the default parameters tabulated on pages 25 through 27 of the GWLF User's Manual, a copy of which can be found in Appendix N (Wu et al., 1989). Yet, these are only approximations of conditions in any watershed, and GWLF model will be most accurate when nutrient data are calibrated to local conditions (Wu et al., 1989).

The GWLF nutrient model requires seven specific nutrient inputs for both Nitrogen and Phosphorus. These inputs are listed below. The model considers dissolved and solid-phase nitrogen and phosphorus in streamflow. Dissolved nutrients are obtained from groundwater, rural runoff and point sources, while solid-phase nutrients are simulated from rural and urban runoff. Rural nutrient loads are transported in runoff water (in the dissolved phase) and eroded soil (in solid-phase) from rural land uses designated within the model input structure. These land uses are assumed to be uniform with respect to soil and cover. Urban nutrient loads, assumed to be entirely solid phase are modeled by exponential washoff functions (Wu et al., 1989). For a discussion of the nutrient model mechanics, please refer to Appendix G.

Dissolved Nitrogen/Phosphorus in Runoff (mg/L):

This input parameter requires the dissolved concentration of nutrients existing within the runoff from each rural land use within the watershed. Default values for this input are tabulated in Table B-3 of the GWLF User's Manual (Appendix N) on page 26 (Wu et al., 1989). For the forest area of the Hadlock Brook Watershed, however, Table B-4 was used and the values of Nitrogen and Phosphorus chosen are 0.19 and 0.006 mg/L, respectively.

Nitrogen/Phosphorus Concentrations in Runoff from Manured Areas (mg/L):

This input calls for the nutrient concentration in the runoff from each rural/agricultural land use which is manured. Default values for this input are tabulated in Table B-3 of the GWLF User's Manual (Appendix N) on page 26 (Wu et al., 1989). This input did not apply to either of the watersheds selected for this study.

Nitrogen/Phosphorus Build-up on Urban Land Uses (kg/ha-day):

This input calls for the urban nutrient accumulation rates (solid-phase) on urban land uses. Default values for this input are tabulated in Table B-2 of the GWLF User's Manual (Appendix N) on page 25 (Wu et al., 1989). Since the Hadlock Brook Watershed contains no urban land uses, this parameter is not applicable to that watershed. Appropriate values for the Old Mill Watershed were selected from Table B-2 (the roads within the Old Mill Brook Watershed were considered to fall under the Industrial category of land use).

Monthly Point Source Nitrogen/Phosphorus (kg):

Point sources are added as constant mass loads (dissolved phase) which are assumed known (Wu et al., 1989). No point sources were contained within the watershed boundaries considered in this study.

Nitrogen/Phosphorus in Groundwater (mg/L):

This input calls for the nutrient concentration in the groundwater (dissolved phase). Default values for this input are tabulated in Table B-4 of the GWLF User's Manual (Appendix N) on page 27 (Wu et al., 1989). The values chosen for the Hadlock Brook watershed correspond to the 90% Forest index and are 0.19 and 0.006 mg/L for Nitrogen and Phosphorus, respectively. Values for the Old Mill Brook Watershed were chosen from the same source.

Nitrogen/Phosphorus in Sediment (mg/kg):

This input requires the value of solid-phase nutrients in sediment from rural sources. This parameter can be estimated as the average soil nutrient content multiplied by an enrichment ratio. Recommended procedures, values and references are given in the GWLF User's Manual (Appendix N) on page 26 (Wu et al., 1989). Estimates of 500 mg/kg were used for both nutrient constituents for the Hadlock Brook Watershed. For the Old Mill Brook watershed, which contains some farmland, the value of the nutrients contained in sediment was estimated to be 1000 mg/kg.

Manure Spreading Period (months):

This input simply requires the specification of the months in which manure is spread. This input is not applicable to this study.

5.2 Discussion of Model Results

The erosion/sediment and hydrology component of the GWLF model (**TRANSPRT.DAT**) along with the nutrient component (**NUTRIENT.DAT**) were applied to the Hadlock Brook and Old Mill Brook watersheds using the input data described above and using both the wet and dry year precipitation data. Hyetographs (precipitation versus time) for the wet and dry years recorded at Acadia National Park Headquarters are in Appendix G.

Output from the GWLF model includes average monthly precipitation (cm), evapotranspiration (cm), groundwater flow (cm), runoff (cm), streamflow (cm), erosion (1000 tonnes), sediment (1000 tonnes), and dissolved and total values of nitrogen and phosphorus (tonnes). Tables 5-5 and 5-6 are the output text files for the GWLF application to the Hadlock Brook and Old Mill Brook Watersheds, respectively, for the wet year. Tables 5-7 and 5-8 represent output text files for the GWLF application to the Hadlock Brook and Old Mill Brook Watersheds, respectively, for the dry year. Since units for all four Tables are in 1000 tonnes, little difference in output values are evident. Output from the actual data files are in kg units and changes are clearly indicated. These are basically system "dumps" and are not shown per se, however, results will be discussed.

The GWLF model output format also provides the amounts of runoff (cm), erosion (tonne/ha) and nutrients (tonnes) coming from each land use within the watershed. This feature could provide park planners with a direct means of ascertaining which land uses represent the greatest threat to receiving water quality. The GWLF model will not only serve as a mechanism for identifying stressed park ecosystems due to urbanization, but it will also allow park planners to foresee, and hopefully avoid, adverse future water quality impacts.

Figures H-1 and I-1 in Appendices H and I show the GWLF simulation of streamflow for the Hadlock Brook and Old Mill Brook watersheds, respectively, for the wet year. A comparison of Appendix G, H, and I shows that the streamflow within the basin approximates the trends of precipitation. This observation explains the relatively high value of streamflow for the month of December generated by the model for both the Hadlock Brook and Old Mill Brook Watersheds, because the hyetograph demonstrates a similar spike in precipitation for that month. The relatively low values of streamflow generated by GWLF for the months of July through October are the result of two unrelated processes. The relatively low precipitation during the Summer months in conjunction with the highest values of evapotranspiration combine to cause the models reasonably low simulation of streamflow.

Figures H-2 and I-2 in Appendices H and I show the GWLF simulation of sediment yield for the Hadlock Brook and Old Mill Brook watersheds, respectively, for the wet year. The sediment yield is the product of erosion and a sediment delivery ratio, and the yield in any month is proportional

Table 5-5. GWLF Output for the Hadlock Brook Watershed Using Wet Year Precipitation.

```
hadbase      1 -year means

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

APR      28.4            1.9          16.9          5.7          22.7
MAY      17.8            5.3          12.7          0.2          13.0
JUNE      3.8           10.3           7.5          0.4           7.9
JULY      9.1           11.6           0.4          0.0           0.4
AUG       8.4           10.0           0.0          1.2           1.3
SEPT      8.4            7.0           0.0          1.2           1.2
OCT      10.1            3.5           0.0          0.7           0.7
NOV      17.9            0.8           3.6          3.1           6.7
DEC      24.6            0.2          11.1          8.1          19.2
JAN      11.9            0.1           6.3          2.2           8.4
FEB      17.0            0.1           4.0          5.6           9.6
MAR      19.8            0.8          19.0         13.6          32.6
-----------------------------------------------------------------
ANNUAL  177.3           51.6          81.5         42.1         123.6

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

APR        0.1       0.0       0.1       0.1       0.0       0.0
MAY        0.0       0.0       0.0       0.0       0.0       0.0
JUNE       0.0       0.0       0.0       0.0       0.0       0.0
JULY       0.0       0.0       0.0       0.0       0.0       0.0
AUG        0.0       0.0       0.0       0.0       0.0       0.0
SEPT       0.0       0.0       0.0       0.0       0.0       0.0
OCT        0.0       0.0       0.0       0.0       0.0       0.0
NOV        0.0       0.0       0.0       0.0       0.0       0.0
DEC        0.0       0.0       0.1       0.1       0.0       0.0
JAN        0.0       0.0       0.0       0.0       0.0       0.0
FEB        0.0       0.0       0.0       0.0       0.0       0.0
MAR        0.0       0.0       0.1       0.1       0.0       0.0
------------------------------------------------------------------
ANNUAL     0.3       0.1       0.4       0.4       0.0       0.1

SOURCE        AREA   RUNOFF   EROSION   DIS.NITR TOT.NITR DIS.PHOS TOT.PHOS
              (ha)    (cm) (tonne/ha)    -----------(tonnes)----------
FOREST         161.   42.12     1.65       0.13     0.17     0.00     0.05
GROUNDWATER                                0.25     0.25     0.01     0.01
POINT SOURCE                               0.00     0.00     0.00     0.00
-------------------------------------------------------------------------
TOTAL                                      0.38     0.42     0.01     0.05
```

Table 5-6. GWLF Output for the Old Mill Brook Watershed Using Wet Year Precipitation.

```
oldmil     1 -year means

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

APR     28.4          1.9         17.4          5.1         22.4
MAY     17.8          5.3         13.0          0.2         13.1
JUNE     3.8         10.3          7.6          0.3          7.9
JULY     9.1         11.6          0.4          0.0          0.4
AUG      8.4         10.0          0.0          1.1          1.1
SEPT     8.4          7.0          0.0          1.1          1.1
OCT     10.1          3.5          0.0          0.6          0.6
NOV     17.9          0.8          4.1          2.8          6.9
DEC     24.6          0.2         11.8          7.5         19.3
JAN     11.9          0.1          6.5          1.9          8.5
FEB     17.0          0.1          4.2          5.3          9.6
MAR     19.8          0.8         19.9         12.7         32.5
---------------------------------------------------------------
ANNUAL 177.3         51.6         84.9         38.5        123.4

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

APR       0.2       0.0       0.5       0.5       0.0       0.0
MAY       0.0       0.0       0.3       0.3       0.0       0.0
JUNE      0.0       0.0       0.2       0.2       0.0       0.0
JULY      0.0       0.0       0.0       0.0       0.0       0.0
AUG       0.0       0.0       0.0       0.0       0.0       0.0
SEPT      0.0       0.0       0.0       0.0       0.0       0.0
OCT       0.0       0.0       0.0       0.0       0.0       0.0
NOV       0.0       0.0       0.2       0.2       0.0       0.0
DEC       0.0       0.0       0.4       0.5       0.0       0.0
JAN       0.0       0.0       0.2       0.2       0.0       0.0
FEB       0.0       0.0       0.2       0.2       0.0       0.0
MAR       0.0       0.0       0.7       0.8       0.0       0.1
----------------------------------------------------------------
ANNUAL    0.4       0.1       2.8       3.0       0.1       0.2

SOURCE       AREA   RUNOFF   EROSION  DIS.NITR TOT.NITR DIS.PHOS TOT.PHO
             (ha)    (cm) (tonne/ha)    ------------(tonnes)----------
FARMLAND         22.   55.85     5.36     0.37     0.40     0.03     0.0
FOREST          636.   37.65     0.37     0.45     0.51     0.01     0.0
INDUSTRIAL        1.   97.68     0.00     0.00     0.05     0.00     0.0
RESIDENTIAL      14.   44.54     0.00     0.00     0.04     0.00     0.0
PAVED ROADS       0.   97.68     0.00     0.00     0.03     0.00     0.0
DIRT ROADS        0.   85.36     0.00     0.00     0.03     0.00     0.0
GROUNDWATER                               1.94     1.94     0.07     0.0
POINT SOURCE                              0.00     0.00     0.00     0.0
-------------------------------------------------------------------------
TOTAL                                     2.77     3.01     0.12     0.2
```

Table 5-7. GWLF Output for the Hadlock Brook Watershed Using Dry Year Precipitation.

```
olddry     1 -year means


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


APR     11.0             1.9          7.9          0.7          8.6
MAY      7.2             5.9          4.8          0.0          4.8
JUNE    10.2             9.2          0.5          0.3          0.9
JULY     5.0            12.3          0.8          0.0          0.8
AUG      5.2             9.3          0.0          0.0          0.0
SEPT    25.0             7.9          0.4          5.7          6.0
OCT      9.7             3.2          3.6          0.1          3.8
NOV     16.3             0.9         11.8          2.3         14.1
DEC     10.8             0.1          5.5          1.3          6.8
JAN      8.6             0.1          5.5          1.1          6.5
FEB     18.3             0.1          2.4          0.2          2.6
MAR      8.6             0.8         13.9         10.7         24.7
-----------------------------------------------------------------
ANNUAL 135.9            51.8         57.1         22.5         79.6

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


APR       0.0       0.0       0.2       0.2       0.0       0.0
MAY       0.0       0.0       0.1       0.1       0.0       0.0
JUNE      0.0       0.0       0.0       0.0       0.0       0.0
JULY      0.0       0.0       0.0       0.0       0.0       0.0
AUG       0.0       0.0       0.0       0.0       0.0       0.0
SEPT      0.2       0.0       0.1       0.2       0.0       0.0
OCT       0.0       0.0       0.1       0.1       0.0       0.0
NOV       0.0       0.0       0.3       0.3       0.0       0.0
DEC       0.0       0.0       0.2       0.2       0.0       0.0
JAN       0.0       0.0       0.2       0.2       0.0       0.0
FEB       0.0       0.0       0.1       0.1       0.0       0.0
MAR       0.0       0.0       0.5       0.6       0.0       0.1
-----------------------------------------------------------------
ANNUAL    0.3       0.1       1.8       2.0       0.1       0.2

SOURCE        AREA   RUNOFF   EROSION  DIS.NITR TOT.NITR DIS.PHOS TOT.PHOS
              (ha)    (cm)  (tonne/ha)    ------------(tonnes)----------
FARMLAND        22.   34.65     4.67      0.23     0.25     0.02     0.04
FOREST         636.   21.87     0.32      0.26     0.31     0.01     0.06
INDUSTRIAL       1.   65.02     0.00      0.00     0.05     0.00     0.00
RESIDENTIAL     14.   26.65     0.00      0.00     0.04     0.00     0.01
PAVED ROADS      0.   65.02     0.00      0.00     0.03     0.00     0.00
DIRT ROADS       0.   55.96     0.00      0.00     0.03     0.00     0.00
GROUNDWATER                               1.31     1.31     0.05     0.05
POINT SOURCE                              0.00     0.00     0.00     0.00
-------------------------------------------------------------------------
TOTAL                                     1.80     2.03     0.08     0.16
```

Table 5-8. GWLF Output for the Old Mill Brook Watershed Using Dry Year Precipitation.

```
haddry     1 -year means


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

APR      11.0            1.9           7.7          0.9           8.7
MAY       7.2            5.9           4.8          0.0           4.8
JUNE     10.2            9.2           0.5          0.4           0.9
JULY      5.0           12.3           0.7          0.0           0.7
AUG       5.2            9.3           0.0          0.0           0.0
SEPT     25.0            7.9           0.0          6.2           6.3
OCT       9.7            3.2           3.4          0.2           3.6
NOV      16.3            0.9          11.5          2.6          14.2
DEC      10.8            0.1           5.3          1.4           6.8
JAN       8.6            0.1           5.3          1.3           6.5
FEB      18.3            0.1           2.3          0.2           2.5
MAR       8.6            0.8          13.3         11.7          25.0
-------------------------------------------------------------------
ANNUAL 135.9            51.8          55.0         25.0          79.9

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

APR        0.0       0.0       0.0       0.0       0.0       0.0
MAY        0.0       0.0       0.0       0.0       0.0       0.0
JUNE       0.0       0.0       0.0       0.0       0.0       0.0
JULY       0.0       0.0       0.0       0.0       0.0       0.0
AUG        0.0       0.0       0.0       0.0       0.0       0.0
SEPT       0.1       0.0       0.0       0.0       0.0       0.0
OCT        0.0       0.0       0.0       0.0       0.0       0.0
NOV        0.0       0.0       0.0       0.0       0.0       0.0
DEC        0.0       0.0       0.0       0.0       0.0       0.0
JAN        0.0       0.0       0.0       0.0       0.0       0.0
FEB        0.0       0.0       0.0       0.0       0.0       0.0
MAR        0.0       0.0       0.1       0.1       0.0       0.0
-------------------------------------------------------------------
ANNUAL     0.2       0.1       0.2       0.3       0.0       0.0

SOURCE        AREA   RUNOFF   EROSION   DIS.NITR TOT.NITR DIS.PHOS TOT.PHOS
              (ha)    (cm)  (tonne/ha)   -----------(tonnes)----------
FOREST          161.   24.96      1.44     0.08     0.11     0.00     0.04
GROUNDWATER                                0.17     0.17     0.01     0.01
POINT SOURCE                               0.00     0.00     0.00     0.00
---------------------------------------------------------------------------
TOTAL                                      0.24     0.28     0.01     0.04
```

to the total transport capacity of daily runoff during the month (Wu et al., 1989). The peaks in the sediment yield correspond to the peaks in the precipitation and streamflow. This is a reasonable correspondence because the sediment yield is a function of runoff and erosion, which are both directly related to the precipitation.

Figures H-3 and H-4 in Appendix H show the Nitrogen and Phosphorus output from the model application to the Hadlock Brook Watershed, respectively, for the wet year. Figures I-3 and I-4 in Appendix I show the Nitrogen and Phosphorus output from the model application to the Old Mill Brook Watershed, respectively, for the wet year. Nutrient concentrations are typically highest in the spring when very little uptake occurs. During the summer months, concentrations generally decrease in response to plant growth and hence uptake. The model suggests this to be the case. Nitrogen exists chiefly in the dissolved phase, therefore little difference between total and dissolved nitrogen predictions. Phosphorus, on the other hand, has a strong affinity for solids. This explains the model predictions which indicate a clear difference between dissolved and total phosphorus.

Figures H-5 through H-8 and I-5 through I-8 indicate similar comparisons for the dry year data.

Results of the monthly graphs can be summarized on an annual basis. Indicated below are the wet and dry year loadings (kgs/year) predicted to be generated from the two watersheds for the current land uses:

HADLOCK BROOK WATERSHED

	Erosion	Sediment	Diss. N	Tot. N	Diss. P	Tot. P
WET	265.6	85.0	378.3	420.8	11.9	54.4
DRY	231.4	74.0	244.7	281.7	7.7	44.8

OLD MILL BROOK WATERSHED

	Erosion	Sediment	Diss. N	Tot. N	Diss. P	Tot. P
WET	353.2	84.8	2765.7	3007.7	119.3	217.1
DRY	307.7	73.8	1799.3	2033.1	77.3	164.6

Since rainfall amount is the model's driving force, loads in all cases are larger for the wet year than the dry year. The different land use characteristics are clearly evident in nitrogen loadings. Old Mill Brook predictions are an order of magnitude larger than the relatively pristine Hadlock Brook watershed. Since the model has undergone little calibration, relative differences between the two watersheds have more meaning than the actual loads.

5.3 Discussion of Model Usefulness

The GWLF model can also be used to address impacts to the watershed's receiving waters (i.e. mass loads exported) as a function of future land use changes. Model simulations indicating detrimental impacts from future land use alternatives would alert park planners to address the significance of these changes and prepare suitable abatement strategies.

An example of how land use changes impact the nutrient loads exported from the watershed was prepared for the Hadlock Brook Watershed. Figures H-3 and H-4 in Appendix I show nitrogen and phosphorus loadings for the current land use conditions of the Hadlock Brook watershed, respectively, during the wet year. The Hadlock Brook watershed consists of approximately 400 acres of forest. In this example, one-quarter of the watershed, approximately 50 acres, was changed to a commercial area, indicative of perhaps some development. Tables 5-9 and 5-10 show the input parameters used to simulate this example for the transport and nutrient components of the model, respectively. Table 5-11 is the output of this example in tabular form as obtained from the GWLF model.

The associated nutrient loadings coming from the new altered watershed are shown in Figures J-1 and J-2 in Appendix J. Development of one-quarter of the watershed yielded an annual increase in total nitrogen of 3.29 tonnes, which correlates to an increase by a factor of nine. Total phosphorus increased from 0.05 to 0.25 tonnes.

HADLOCK BROOK WATERSHED - WET YEAR

	Erosion	Sediment	Diss. N	Tot. N	Diss. P	Tot. P
CURRENT	265.6	85.0	378.3	420.8	11.9	54.4
ALTERED	199.7	63.9	318.6	3,709.7	10.1	248.9

Significant increases in total N and P are observed for the altered watershed while erosion and sediment indicate small decreases, as expected.

As noted earlier, output predicted by the model cannot be assigned a degree of confidence unless some calibration is performed. Since water flow rates are used for determining many of the export loads, this would be one parameter worthy of calibration. In order to obtain

Table 5-9. GWLF Input: Hydrology and Erosion/Sediment Component for Hypothetical Development Within the Hadlock Brook Watershed.

TRANSPRT DATA

LAND USE	AREA(ha)	CURVE NO	KLSCP
FOREST	121.	76.0	0.00400
Commercial	40.	90.0	0.00000

MONTH	ET CV()	DAY HRS	GROW. SEASON	EROS. COEF
APR	0.510	13.2	0	.229
MAY	0.850	14.5	1	.229
JUNE	0.980	15.2	1	.229
JULY	1.000	14.8	1	.229
AUG	1.020	13.7	1	.229
SEPT	1.030	12.3	1	.229
OCT	1.010	10.8	1	.076
NOV	0.500	9.5	0	.076
DEC	0.440	8.8	0	.076
JAN	0.490	9.2	0	.076
FEB	0.510	10.3	0	.076
MAR	0.510	11.7	0	.076

ANTECEDENT RAIN+MELT FOR DAY -1 TO DAY -5
0 0 0 2.03 0

INITIAL UNSATURATED STORAGE(cm) = 0
INITIAL SATURATED STORAGE(cm) = 2.7
RECESSION COEFFICIENT = .1
SEEPAGE COEFFICIENT = 0
INITIAL SNOW(cm water) = 0
SEDIMENT DELIVERY RATIO = 0.320

Table 5-10. GWLF Input: Nutrient Component for Hypothetical Development Within the Hadlock Brook Watershed.

```
NUTRIENT DATA

LAND USE              DIS.NITR IN RUNOFF(mg/l)        DIS.PHOS IN RUNOFF(mg/l
FOREST                      .19                             .006

LAND USE              NITR.BUILD-UP(kg/ha-day)        PHOS.BUILD-UP(kg/ha-day
Commercial                  .237                            .0146

MONTH                 POINT SOURCE NITR.(kg)          POINT SOURCE PHOS.(kg)
APR                         0                               0
MAY                         0                               0
JUNE                        0                               0
JULY                        0                               0
AUG                         0                               0
SEPT                        0                               0
OCT                         0                               0
NOV                         0                               0
DEC                         0                               0
JAN                         0                               0
FEB                         0                               0
MAR                         0                               0

NITROGEN IN GROUNDWATER(mg/l):        0.190
PHOSPHORUS IN GROUNDWATER(mg/l):      0.006
NITROGEN IN SEDIMENT(mg/kg):         500
PHOSPHORUS IN SEDIMENT(mg/kg):       500
```

Table 5-11. GWLF Output for Hypothetical Development within the Hadlock Brook Watershed using Wet Year Precipitation Data.

```
example     1 -year means


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

APR      28.4             1.9         15.8          7.5          23.3
MAY      17.8             5.3         12.0          0.6          12.7
JUNE      3.8            10.3          7.0          0.6           7.6
JULY      9.1            11.6          0.3          0.2           0.5
AUG       8.4            10.0          0.0          1.7           1.7
SEPT      8.4             7.0          0.0          1.7           1.7
OCT      10.1             3.5          0.0          1.2           1.2
NOV      17.9             0.8          1.9          4.2           6.1
DEC      24.6             0.2          9.3          9.3          18.6
JAN      11.9             0.1          5.6          2.8           8.4
FEB      17.0             0.1          3.5          6.1           9.6
MAR      19.8             0.8         17.0         15.7          32.7
------------------------------------------------------------------------
ANNUAL 177.3             51.6         72.4         51.5         124.0

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

APR       0.1       0.0       0.1       0.3       0.0       0.0
MAY       0.0       0.0       0.0       0.3       0.0       0.0
JUNE      0.0       0.0       0.0       0.1       0.0       0.0
JULY      0.0       0.0       0.0       0.3       0.0       0.0
AUG       0.0       0.0       0.0       0.5       0.0       0.0
SEPT      0.0       0.0       0.0       0.3       0.0       0.0
OCT       0.0       0.0       0.0       0.2       0.0       0.0
NOV       0.0       0.0       0.0       0.4       0.0       0.0
DEC       0.0       0.0       0.0       0.3       0.0       0.0
JAN       0.0       0.0       0.0       0.4       0.0       0.0
FEB       0.0       0.0       0.0       0.3       0.0       0.0
MAR       0.0       0.0       0.1       0.3       0.0       0.0
-----------------------------------------------------------------
ANNUAL    0.2       0.1       0.3       3.7       0.0       0.2

SOURCE        AREA    RUNOFF   EROSION   DIS.NITR TOT.NITR DIS.PHOS TOT.PHOS
              (ha)     (cm)  (tonne/ha)   -----------(tonnes)----------
FOREST          121.   42.12      1.65      0.10      0.13      0.00      0.04
Commercial       40.   80.04      0.00      0.00      3.36      0.00      0.21
GROUNDWATER                                 0.22      0.22      0.01      0.01
POINT SOURCE                                0.00      0.00      0.00      0.00
--------------------------------------------------------------------------------
TOTAL                                       0.32      3.71      0.01      0.25
```

volumetric flow rate units (L^3/T) for the values of groundwater, runoff and streamflow, the monthly averages with units of centimeters (L) must be multiplied by the area of the watershed (L^2) and divided by the desired unit of time within the month (T).

For example, in the Hadlock Brook Watershed simulation for the 'wet year', the average streamflow value output from the GWLF model for the month of May is approximately 13 cm. This value can be converted to a average volumetric flow rate (cfs) by:

$$\frac{(13\text{cm})\ (\text{in}/2.54\text{cm})\ (\text{ft}/12\text{in})\ (398.1\text{ac})\ (43560\text{ft}^2/\text{ac})}{(\text{month of May})\ (31\text{days/month of May})\ (86{,}400\text{sec/day})}$$

= 2.76 cfs.

It is through this type of conversion that the GWLF model can be calibrated. A simple flow monitoring effort consisting of flow readings at the design location at both relatively high and low flow periods can provide an actual measured average flow which can then be compared to the simulated values of flow generated by the GWLF model. From the sensitivity analysis (see section 5.4), the input parameters which affect the GWLF simulations of streamflow can be determined and from that information defendable changes can be made to the GWLF input structure so that the measured and simulated values of average streamflow coincide from month to month.

A similar approach can be used to calibrate the water quality components of the GWLF model.

5.4 Sensitivity Analysis

In this section, appropriate input parameters for the **TRANSPRT.DAT** data file for the Hadlock Brook Watershed simulation during the wet year are individually varied for a single land use and the relative effects to the model output are observed and discussed. This analysis was applied to the base values of the input structure determined for the Hadlock Brook Watershed as described in the parameter derivation section (Section 5.1). A sensitivity analysis is important because it serves to provide information on the relative accuracy with which input parameters should be estimated. If small variation of a particular parameter indicate large changes in output, clearly a means of estimating that parameter with a high degree of accuracy is necessitated. If however, large variations of a parameter results in insignificant model response, an accurate estimation of that parameter is not necessary. This has significance on how rapidly a model input set can be prepared for a particular scenario.

As discussed in Section 5.2, basic output from the GWLF model (when nutrient loadings are not considered) includes average monthly precipitation (cm), evapotranspiration (cm), groundwater flow (cm), runoff (cm), streamflow (cm), erosion (1000 tonnes) and sediment (1000 tonnes). Only the streamflow and sediment outputs were considered in this study because these are direct predictions. Nutrients loads were based on these predictions.

The sensitivity analysis applied to the input parameters are shown graphically in Appendix K. In these plots, the input value listed first in the legend represents the base value of the parameter which was derived in section 5.1. Graphs of the sensitivity analysis were only constructed for the specific model output (i.e. streamflow or sediment) which was affected by the variation of the input parameter. For instance, the variation of the sediment delivery ratio would most certainly affect the model's prediction of the amount of sediment that would come off the watershed, but it would not affect the model's simulation of streamflow. In the aforementioned example, a graphical analysis would be applied only to the models response of the sediment yield. If a graph is not included for a specific input parameter's effect on a certain output, it can be assumed that the variation of the input parameter did not deviate the models response from that of the original input structure.

CN:

Figures K-1 and K-2 indicate effect of Curve Number (CN) on stream flow and sediment, respectively.

KLSCP:

The KLSCP factor has a significant affect on the sediment output from the model. Figure K-3 demonstrates that increasing the KLSCP factor will increase the mass loadings of sediment. This relationship is expected since increasing the KLSCP factor will increase the amount of sediment from each land use within the basin. Greater amounts of erosion means that there is more dislodged material available for transport through runoff as sediment. This parameter is an important input which should be determined very carefully.

Monthly Evapotranspiration Cover Coefficient:

The GWLF model requires monthly values of the evapotranspiration cover coefficient. In this sensitivity analysis the evapotranspiration cover coefficient was varied for the month of September. Figure K-4 shows that increasing the evapotranspiration cover coefficient for one month allows water to escape the system via evapotranspiration at a time lag depending on the amount of precipitation. In this example the lag was two months, and the higher values of the evapotranspiration cover coefficients correspond to larger amounts of water lost due to evapotranspiration, which in turn yields lower streamflow when all other parameters are held constant.

The evapotranspiration cover coefficient is not a very sensitive parameter in that its fluctuation only effects the streamflow output by a relatively small amount and for a one month period. Since this coefficient is used as a means of linearly relating the watershed evapotranspiration with the potential evapotranspiration, values of the evapotranspiration cover coefficient greater than a few hundredth over unity would be unreasonable. As this parameter is difficult to measure directly, however, it could be used as a 'fine tuning' calibration parameter within reasonable values.

Average Monthly Daylight Hours:

The GWLF model requires monthly values of the average daylight hours. In this sensitivity analysis the average monthly daylight hours parameter was varied for the month of September. Figure K-5 shows that increasing the average monthly daylight hours for one month allows water to escape the system via evapotranspiration at a time lag depending on the amount of precipitation. In Figure K-4, the lag was two months, and the higher values of the average monthly daylight hours correspond to larger amounts of water lost due to evapotranspiration, which in turn yields lower streamflow when all other parameters are held constant.

This parameter is not useful as a calibration tool because the average monthly hours of daylight are easily obtained from reference materials with a good deal of accuracy. Furthermore, the margin for reasonable values is quite small and is usually close to twelve hours at the latitude of 44°N which is the approximate location of Mount Desert Island. From Figure K-5, it can be seen that the model is relatively insensitive to changes in this input parameter from zero hours of daylight to sixteen hours of daylight.

Monthly Growing Season Flag (0,1):

Figures K-6 and K-7 demonstrate that the growing season parameter is not of much use as a calibration tool. Furthermore, it is readily determined from the definition of a growing season given in the GWLF User's Manual whether a month should be categorized as a growing season based on the mean daily air temperature, with dormant months being those with mean temperatures below 10°C (Wu et al., 1989).

Because the growing season parameter affects the runoff from the watershed, variation of this parameter has an effect on sediment yield as well as streamflow.

Monthly Erosion Coefficient:

This input parameter is used in conjunction with the KLSCP factor to generate erosion loads. Figure K-8 shows the monthly erosion coefficients limited use as a calibration tool. This parameter was varied for the month of September with little effect on the model's simulation of sediment yield.

Initial Saturated Storage (cm):

From Figure K-9 it can be seen that this input parameter only affects the first months prediction of streamflow and therefore can be considered an insensitive calibration tool.

Recession Coefficient:

The recession constant (r) is an important parameter in the ground water/hydrologic budget portion of the GWLF model as explained in section 5.1. The recession constant is the decay coefficient used by the model when predicting the shallow saturated zone moisture level at various times throughout the duration of simulation. The recession constant also governs how much of the moisture within the saturated zone is discharged via groundwater to the stream. Figure K-10 demonstrates this nonlinear relationship between the recession constant and the streamflow. This nonlinearity is evidenced by the overlapping of the unit recession constant with the base value corresponding to a recession constant of 0.1.

Estimates of the recession constant r can be estimated from streamflow records by standard hydrograph separation techniques (Chow, 1964) as alluded to in section 5.1 and explained in greater detail in the GWLF User's Manual (Wu et al., 1989). Therefore, there is a standard technique for the determination of the Recession Constant, and this input should be determined carefully because the

GWLF is very sensitive to variations in this groundwater parameter.

Seepage Coefficient:

This input parameter governs the amount of water which is lost from the system via percolation to the deep saturated zone. The parameter linearly relates the moisture content of the shallow saturated zone to the amount of water from the shallow saturated zone which percolates to the deep saturated zone. Therefore, the only reasonable values of the seepage constant range from 0 (no moisture is lost to the deep saturated zone) to 1 (all of the water in the shallow saturated zone is lost to percolation to the deep saturated zone, and more significantly, no water is available as groundwater inflow to the stream). Figure K-11 demonstrates these two scenarios along with the a value of the seepage constant which falls between the two extremes. Accordingly, the seepage constant of zero yields the highest streamflow values because all of the water in the shallow saturated zone is available as groundwater to the stream. Alternatively, the seepage constant of unity yields the lowest values of streamflow for the reasons discussed above.

This input is a very powerful calibration tool because the streamflow output of the GWLF model is very sensitive to the variations of the seepage constant. In addition, there is no standard technique available for estimating the seepage constant (Wu et al., 1989).

Sediment Delivery Ratio:

The sediment delivery ratio is a good calibration parameter for calibrating the sediment output from the GWLF model. Sediment yield within the GWLF model is generated as the product of erosion and the sediment delivery ratio, and the yield in any month is proportional to the total transport capacity of daily runoff during the month (Wu et al., 1989). Although the sediment yield in Figure K-12 does not vary dramatically with fluctuating sediment delivery ratios, the output does show sensitivity. The value of this input parameter is read from a graph (Figure B-1 in the GWLF User's Manual) and is therefore subject to some variability.

As summarized in the following list, it appears that GWLF output is quite sensitive to three input parameters; accurate estimation of these three is crucial to the model's success.

HIGHLY SENSITIVE PARAMETER	RELATIVELY INSENSITIVE PARAMETER
KLSCP	Monthly Evaporation Cover Coefficient
Recession Coefficient	Average Monthly Daylight Hours
Seepage Coefficient	Monthly Growing Season Flag
	Monthly Erosion Coefficient
	Initial Saturated Storage

CHAPTER 6
CONCLUSIONS

6.1 Summary and Conclusions:

A number of nonpoint source computer simulation models were evaluated and judged on their applicability to assessing nonpoint source loads in watersheds within Acadia National Park, Maine. Criteria included applicability to the geography and hydrology of Acadia, ease of application of the model (user friendliness), extent of data requirements, and the ability to handle changes in land use. One model emerged as most suitable; the Generalized Watershed Loading Functions Model (GWLF).

GWLF was subjected to a review and an attempt was made to apply it to several representative watersheds within Acadia to exemplify its use. Three watersheds were selected chiefly due to their different land use characteristics. Considerable effort was expended on collecting required input data. Due to a current lack of some crucial model input data, testing could only be performed on two watersheds.

The model required a fair amount of data reduction and data preparation for simulations. Geographical Information System (GIS) files were not available hence all input parameters were derived manually. The model performed as expected providing long term (continuous) simulations for a number of parameters including stream flows, sediment loads, nitrogen loads, and phosphorus loads.

A sensitivity analysis was performed on the model to determine model output sensitivity on the various input parameters. Three parameters were found to be important with accurate assessment of these crucial to model success.

There is currently no capability of GWLF to obtain information directly from a GIS package such as ARC/INFO. However, as indicated earlier, model developers are presently experimenting with an external interface to mate output of a GIS to GWLF requirements. This capability would substantially decrease the efforts necessary to prepare input data sets.

6.2 Recommendations for Future Needs:

This preliminary study has only considered three watersheds within Acadia National Park. For any model to be useful as a comprehensive planning tool, the entire Park must be considered along with outside areas which may impact the Park's water resources. This would involve additional efforts. Tasks would include the delineation of all watersheds within the Park and those outside the Park's boundaries which indicate overland runoff patterns that may impact the Park's water resources. Next, model parameters described in Chapter 5 would have to be determined for all watersheds. If completed, the ArcInfo coverages generated by the COA would greatly facilitate this task. The sensitivity analysis performed herein has already demonstrated which parameters warrant particular attention.

The model could be utilized for the different annual precipitation data available from the local precipitation gaging station. Data regarding zoning and prospective future development areas could be obtained from local authorities and used to construct realistic future land use changes to be considered by the model. Output from the model simulations would provide Park managers with several important pieces of information including an overall view of impacts to the entire Park and a ranking identifying the most impacted watersheds/areas. Additionally, the model could be used to simulate possible mitigation strategies such as varying zoning densities.

Based on the work performed, a list of additional items which have emerged as being important to strengthening model performance are as follows.

1. The compilation of data necessary for the modeling effort requires an enormous amount of time. No doubt the usefulness and future applicability of nonpoint source models depends in part on the ease with which accurate data can be assembled for the required input requirements. With the data available in one source or location more time can be spent actually "modeling". It is the opinion of the authors that a Geographical Information System (GIS) has the potential for providing this link. Land use is perhaps the component to benefit most.

Concurrent with this study, the College of the Atlantic (COA) in Bar Harbor, Maine, is digitizing all existing data regarding land use, zoning, soil types, and other parameters with the ARC/INFO GIS package. Once these data becomes available in digitized format, much of the data gathering process could be eased.

2. Model calibration is an important step in any computer simulation. To properly calibrate the stream flow and runoff quality predictions, actual hydrographs during both dry conditions and several wet weather events are necessary. While GWLF is primarily a continuous simulation model, calibration to a set of existing conditions would greatly defend the accuracy of the model predictions. These data can provide magnitudes of flow for given precipitation amounts and insight on items such as actual recession constants, an important and sensitive model parameter. If water quality (especially nutrient) data are collected in conjunction with the flow effort, mass loads can be developed and used to calibrate the water quality (nutrient) portion of GWLF.

Ideally, one downstream sampling location should be established in all watersheds within the Park. If resources are not available, then at a minimum representative watersheds should be selected so as to include all possible land use types. For the dry weather conditions (no overland runoff) selected sites should be monitored approximately every two weeks for selected constituents and flow. Constituents may include chloride, sodium, TSS, VSS, nitrate+nitrite, orthophosphate, ammonia, total nitrogen, total phosphorus, calcium, magnesium, lead, nickel, and copper, as well as field determined parameters such as temperature, pH, specific conductance, and dissolved oxygen (DO). DO should be determined approximately four times per day for maximum effectiveness.

Wet weather sampling should occur for at least three distinct storm events of different magnitude to determine quantity and quality of overland runoff. Establishment of a priori rainfall criteria would be necessary and may include minimum rainfall amounts, minimum duration, and minimum antecedent dry period. Actual water quality sampling should include one pre-storm sample and a number of sample throughout the duration of the rainfall induced hydrograph.

3. A range of scenarios with changes in land use in the watersheds should be generated to provide a matrix of impacts versus land use. This important exercise would provide insight on the degree to which particular land use types would impact the water resources.

4. With some calibration of the model at Acadia using a comprehensive set of field data, the relative effectiveness and accuracy of GWLF simulations can be estimated. In turn, the GWLF modeling concept could be applied to other Parks within National Park Service jurisdiction to provide baseline simulations as well as

"changed land use" simulations. Some measure of credibility might be estimated without the need for comprehensive data collection at these other sites.

5. The work presented herein has provided a wealth of knowledge regarding nonpoint source loading models. The transferability of GWLF to other areas within the National Park Service is possible. As noted, an important item to address is the collection of input data requirements. The authors are aware of the Park Service using ARC/INFO in other areas. GWLF does not presently contain provision for direct data input from a GIS. Even so, data available from one sole source would be beneficial. Furthermore, the development of a capability to directly incorporate GIS data could greatly facilitate the ease with which such a model could be applied as a management tool.

CHAPTER 7
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CHAPTER 8
APPENDICES

Appendix A

Preliminary Evaluation of the Nonpoint Source Runoff Model

Hydrological Simulation Program-FORTRAN (HSPF)

Characteristic	Summary Information
Source	-Developed for the EPA, 1981 (Barnwell and Johanson, 1981; Donigian et al., 1984). -User's Manual available from the NTIS, EPA-600/3-84-066.
Applicable Land Drainage Area	-Urban, Agriculture, Forest/Natural
Inputs	-Time series meteorologic and hydrologic data, land use, Best Management Practices (BMPs), watershed data. For a complete list of HSPF inputs refer to Table A-1.
Outputs	-Continuous hydrologic simulation, annual loads, event loads, behavior of pollutants in runoff and receiving waters, evaluation of BMP effectiveness
Comments	-HSPF performs the simulation on a lumped parameter concept, whereby magnitudes of parameters must be determined by calibration. -HSPF has continuous and event simulation capabilities. -"HSPF includes time series-based simulation modules (PERLIND, IMPLND, and RCHRES), and utility modules (COPY, PLTGEN, DISPLAY, DURANL, and GENER). Refer to Figure A-1 for a descriptive listing of HSPF modules. The simulation (application) modules include mathematics for the behavior of processes that occur in a study watershed. The watershed is divided into three

Appendix A Continued

Preliminary Evaluation of the Nonpoint Source Runoff Model

Hydrological Simulation Program-FORTRAN (HSPF)

Comments (cont.)	segments -- pervious land, impervious land, and a receiving water system (i.e., a single reach of an open channel or a completely mixed impoundment). The module PERLND simulates the pervious land segment with snow accumulation and melt, water movement (overland flow, interflow, and groundwater flow), sediment erosion and scouring, and water quality (pesticides, nutrients). The IMPLND module simulates the impervious land segment where little or no infiltration occurs. The IMPLND processes include snow and water movements, solids and water quality constituents. The module RCHRES simulates the segment of receiving water body, including hydraulic behavior, conservative and nonconservative constituents, temperature, sediments, BOD and DO, nitrogen, phosphorus, carbon, and pH. The utility modules perform "house-keeping" operations, designed to provide the user flexibility in managing simulation inputs and outputs" (Schnoor et al., 1987). -Water quality constituents can be modeled as attached or adsorbed on the sediment. -A complex model requiring substantial training and computer resources. -Extensive documentation use, and support.

Appendix A Continued

Preliminary Evaluation of the Nonpoint Source Runoff Model **Hydrological Simulation Program-FORTRAN (HSPF)**

Comments (cont.)	-Requires very detailed input data. -PC versions of HSPF are distributed on 6 diskettes (IEP, 1990). -An interface between an ARC/INFO GIS and the HSPF watershed model is being developed (Fisher, 1989) -HSPF is a large model requiring a considerable effort in preparation of data input and the user should not be limited by the computer storage and time availability (Novotny, 1986) -Presently, HSPF includes modules which can handle almost all the functions which are available in the following existing models (Johanson et al., 1984): (1) HSP--Hydrocomp Simulation Model (2) ARM--Agricultural Runoff Model (3) NPS--Nonpoint Source Pollution Model

APPLICATION MODULES

PERLND	IMPLND	RCHRES
Snow	Snow	Hydraulics
Water	Water	Conservative
Sediment	Solids	Temperature
Quality	Quality	Sediment
Pesticides		Nonconservative
Nitrogen		BOD/DO
Phosphorus		Phosphorus
Tracer		Carbon
		Plankton

UTILITY MODULES

COPY	PLTGEN	DISPLY
Data Transfer	Plot Data	Tabulate and Summarize

DURANI	GENER
Duration Analysis	Transform and Combine

Figure A-1. Modules of the HSPF Hydrological Model (from Novotny, 1986).

Table A-1. Complete listing of HSPF input structure (Schnoor et al., 1987).

INPUTS TO PERLND

(1) Inputs to correct air temperature for elevation difference.

- Difference in elevation between the temperature gage and the pervious land segment.
- Air temperature over the pervious land segment.

(2) Inputs to simulate accumulation and melting of snow and ice.

- Latitude of the pervious land segment.
- Mean elevation of the pervious land segment.
- Fraction of the pervious land segment which is shaded from solar radiation by, for example, trees.
- Maximum pack (water equivalent) at which the entire pervious land segment will be covered with snow.
- Density of cold, new snow relative to water.
- Air temperature below which precipitation will be snow, under saturated conditions.
- A parameter which adapts the snow evaporation equation to field conditions.
- A parameter which adapts the snow condensation/convection melt equation to field conditions.
- Maximum water content of the snow pack, in depth water per depth water equivalent.
- Maximum rate of snowmelt by ground heat, in depth of water equivalent per day.
- Quantities of snow, ice and liquid water in the pack (water equivalent).
- Density of the frozen contents (snow + ice) of pack, relative to water.
- Mean temperature of the frozen contents of the pack.
- Current pack (water equivalent) required to obtain complete areal coverage of the pervious land segment.
- Current remaining possible increment to ice storage in the pack.
- Fraction of sky which is assumed to be clear at the present time.

(3) Inputs to simulate water budget for pervious land segment.

- Fraction of the pervious land segment which is covered by forest which will continue to transpire in winter.
- Lower zone nominal storage
- Length and slope of the assumed overland flow plane
- Basic groundwater recession rate.
- Air temperature below which evapotranspiration will arbitrarily be reduced below the value obtained from the input time series.

Table A-1. Continued.

- Temperature below which evapotranspiration will be zero regardless of the value in the input time series.
- Exponent in the infiltration equation.
- Ratio between the max and mean infiltration capacities over the pervious land segment.
- Fraction of groundwater inflow which will enter deep (inactive) groundwater and, thus, be lost from the system.
- Fraction of remaining potential evapotranspiration which can be satisfied from baseflow (groundwater outflow), if enough is available.
- Fraction of remaining potential evapotranspiration which can be satisfied from active groundwater storage if enough is available.
- Interception storage capacity.
- Upper zone nominal storage.
- Manning's n for the assumed overland flow plane.
- Interflow inflow and recession parameters.
- Lower zone evapotranspiration parameter.
- Monthly interception storage capacity.
- Monthly upper zone storage.
- Monthly Manning's n values.
- Monthly interflow parameters.
- Monthly interflow recession constants.
- Monthly lower zone evapotranspiratino parameter.
- Interception storage.
- Surface (overland flow) storage.
- Storages of upper, lower and interflow zones.
- Active groundwater storage.
- Surface storage (upper zone and interflow).

(4) Inputs to produce and remove sediment.

- Supporting management practice factor. It is used to simulate the reduction in erosion achieved by use of erosion control practices.
- Coefficient in the soil detachment equation.
- Exponent in the soil detachment equation.
- Fraction by which detached sediment storage decreases eaach day, as a result of soil compaction.
- Fraction of land surface which is shielded from erosion by rainfall.
- Rate at which sediment enters detached storage from the atmosphere.
- Coefficient and exponent in the detached sediment washoff equation.
- Coefficient and exponent in the matrix soil scour equation.
- Monthly erosion related cover values.
- Monthly net vertical sediment input.
- Initial storage of detached sediment.

Table A-1. Continued.

(5) Inputs to estimate soil temperature.

- Surface layer temperature, when the air temperature is 32 degrees F (ASLT).
- Slope of the surface layer temperature regression equation (BSLT).
- Smoothing factor in upper layer temperature calculation (ULTP1).
- Mean difference between upper layer soil temperature and air temperature (ULTP2).
- Smoothing factor for calculating lower layer/groundwater soil temperature (UGTP1).
- Mean departure from air temperature for calculating lower layer/groundwater soil temperature (UGTP2).
- Intercept in the upper layer soil temperature regression equation.
- Slope in the upper layer soil temperature regression equation.
- Monthly values for ASLT, BSLT, ULTP1, ULTP2, LGTP1, and LGTP2.
- Initial air temperature.
- Initial surface layer soil temperature.
- Initial upper layer soil temperature.
- Initial layer/groundwater layer soil temperature.

(6) Inputs to estimate water temperature and dissolved gas concentrations.

- Elevation of the pervious land segment above seal level.
- Concentration of dissolved oxygen nd CO2 in interflow outflow, and in active groundwater flow.
- Monthly interflow DO and CO2 concentrations.
- Monthly groundwater DO and CO2 concentrations.
- Initial surface and interflow outflow temperature.
- Initial active groundwater outflow temperature.
- Initial DO and CO2 concentrations in surface outflow, interflow outflow, and active groundwater outflow.

(7) Inputs to simulate quality constituents using simple relationships with sediment and water yield.

- Washoff potency factor.
- Scour potency factor.

  Note: A potency factor is the ratio of constituent yield to sediment (washoff or scour) outflow.
- Initial storage of constituent on the surface of the pervious land segment.
- Rate of accumulation of constituent.
- Maximum storage of constituent.
- Rate of surface runoff which will remove 90 percent of stored constituent per hour.
- Concentration of the constituent in interflow outflow.
- Concentration of the constituent in active groundwater outflow.
- Monthly washoff and scour potency factors.
- Monthly accumulation rates of constituent.
- Monthly limiting storage of constituent.

- Monthy concentrations of constituent in interflow and groundwater.

(8) Inputs to estimate the moisture and fractions of solutes being transported in the soil layers.

- Nominal upper and lower zones storage.
- Initial surface detention storage.
- Initial surface detention storage on each block of the pervious land segment.
- Initial moisture content in the surface storage, in the upper principal storage, and in the upper transitory (interflow) storage.
- Initial moisture storages in the lower layer, and in the active groundwater layer.

(9) Inputs to simulate pesticide behavior in detail.

- Chemical first-order reaction temperature correction parameters which is used to adjust the desorption and adsorption rates.
- Desorption and adsorption rates (first-order) at 35°C.
- Maximum solubility of the pesticide in water.
- Maximum concentration (on the soil) of pesticide which is permanently fixed to the soil.
- Coefficient and exponent parameters for the Freundlich adsorption-desorption equation.
- Pesticides degradation rates in the surface, upper, and active groundwater layers.
- Initial storage of pesticide in crystalline adsorbed and solution forms in surface, upper, lower or groundwater layer.
- Initial storage of pesticide in the upper layer transitory (interflow) storage.

(10) Inputs to simulate nitrogen behavior in detail.

- Plant nitrogen uptake reaction rate parameters for the surface layer, upper layer, lower layer, and active groundwater layer.
- Monthly plant uptake parameters for nitrogen, for the surface, upper, lower or groundwater layer.
- Parameters intended to designate which fraction of nitrogen uptake comes from nitrite and ammonium.
- Temperature coefficients for plant uptake, ammonium desorption, ammonium adsorption, nitrate immobilization, organic N ammonification, NO3 denitrification, Nitrification, and ammonium immobilization.
- Maximum solubility of ammonium in water.
- Initial storage of N in organic N, adsorbed ammonium, nitrate, and plants.
- Initial storages of ammonium and nitrate in the upper layer transitory (interflow) storage.

Table A-1. Continued.

(11) Inputs to simulate phosphorus behavior in detail.

- Plant phosphorus uptake reaction rate parameters for the surface layer, upper layer, lower layer, and active groundwater layer.
- Monthly plant uptake parameters for phosphorus, for the surface, upper, lower or groundwater layer.
- Temperature correction parameters for phosphorus plant uptake, phosphate desorption, phosphate immobilization, and organic P mineralization.
- First-order reaction rates for phosphate desorption, phosphate adsorption, phosphate immobilization, and organic P mineralization.
- Maximum solubility of phosphorus in water.
- Initial phosphorus storage (in organic P, adsorbed P, solution P, and P stored in plants) in the surface, upper, lower or groundwater layer.
- Initial storage of phosphate in upper layer transitory (interflow) storage.

(12) Inputs to simulate the movement of a tracer (conservative).

- Initial storage of tracer (conservative) in the surface storage, upper principal storage, upper transitory storage, lower groundwater layer, and active groundwater layers.

INPUTS TO IMPLND

(1) Inputs to correct air temperature for elevation difference.

- See temperature inputs in the PERLAND section.

(2) Inputs to simulate the accumulation and melting of snow and ice.

- See snow inputs in the PERLND section.

(3) Inputs to simulate water budget for impervious land segment.

- Length and slope of the assumed overland flow plane.
- Manning's n for the overland flow plane.
- Retention (interception) storage capacity of the surface.
- Air temperature below which evapotranspiration will arbitrarily be reduced below the value obtained from the input time series.
- Temperature below which evapotranspiration will be zero regardless of the value in the input time series.
- Monthly retention storage capacity.
- Monthly Manning's n values.
- Initial retention storage.
- Initial surface (overland flow) storage.

(4) Inputs to estimate accumulation and removal of solids.

- Coefficient in the solids washoff equation.

Table A-1. Continued.

- Exponent in the solids washoff equation.
- Rate at which solids are placed on the land surface.
- Fraction of solids storaage which is removed each day; when there is no runoff, for example, because of street sweeping.
- Monthly solids accumulation rates.
- Monthly solids unit removal rates.
- Initial storage of solids.

(5) Inputs to estimate water temperature and dissolved gas concentrations.

- Elevation of the impervious land segment above sea level.
- Surface water temperature, when the air temperature is 32°F (AWTF).
- Slope of the surface water temperature regression equation (BWTF).
- Monthly values for AWTF and BWTF.
- Initial values for the temperature, DO and CO2.

(6) Inputs to simulate quality constituents using simple relationships with solids and/or water yield.

- Washoff potency factor.
- Initial storage of constituent on the surface of the impervious land segment.
- Rate of accumulation of constituent.
- Maximum storage of constituent.
- Rate of surface runoff which will remove 90 percent of stored constituent per hour.

INPUT TO RCHRES

(1) Inputs to simulate hydraulic behavior.

- Length of the receiving water body (RCHRES).
- Drop in water elevation from the upstream to the downstream extremities of the RCHRES.
- Correction to the RCHRES depth to calculate stage.
- Weighting factor for hydraulic routing.
- Median diameter of the bed sediment (assumed constant throughout the run).
- Initial volume of water in the RCHRES.

(2) Inputs to prepare to simulate advection of entrained constituents.

- Ration of maximum velocity to mean velocity in the RCHRES cross section under typical flow conditions.
- Volume of water in the RCHRES at the start of the simulation.

(3) Inputs to simulate behavior of conservative constituents.

- Initial concentration of the conservative.

Table A-1. Continued.

(4) Inputs to simulate heat exchange and water temperature.

- Mean RCHRES elevation.
- Difference in elevation between the RCHRES and the air temperature gage.
- Correction factor for solar radiation.
- Longwave radiation coefficient.
- Conduction-convection heat transport coefficient.
- Evaporation coefficient.
- Water temperature at the RCHRES.
- Air temperature at the RCHRES.

(5) Inputs to simulate behavior of inorganic sediment.

- Width of the cross-section over which HSPF will assume bed sediment is deposited regardless of stage, top-width, etc.
- Bed depth.
- Porosity of the bed (volume voids/total volume).
- Effective diameter of the transported sand, silt and clay particles.
- Fall velocity of the sand, silt and clay particles in still water.
- Density of the sand, silt and clay particles.
- Critical bed shear stresses for deposition and scour.
- Erodibility coefficient of the sediment.
- Initial concentrations (in suspension) of sand, silt, and clay.
- Initial total depth (thickness) of the bed.
- Initial fractions (by weight) of sand, silt and clay in the bed material.

(6) Inputs to simulate behavior of a generalized quality constituent.

- Latitude of the RCHRES.
- Initial concentration of constituent.
- Second order acid and base rate constants for hydrolysis.
- First order rate constant of neutral reaction with water.
- Temperature correction coefficient for hydrolysis.
- Second order rate constant for oxidation by free radical oxygen.
- Temperature correction coefficient for oxidation by free radical oxygen.
- Molar absorption coefficients for constituent for 18 wavelength ranges of light.
- Quantum yield for the constituent in air-saturated pure water.
- Temperature correction coefficient for photolysis.
- Ratio of volatilization rate to oxygen reaeration rate.
- Second order rate constant for biomass concentration causing biodegradatino of constituent.
- Temperature correction coefficient for biodegradation of constituent.
- Concentration of biomass causing biodegradation of constituent.
- Monthly concentration of biomass causing biodegradation of constituent.

Table A-1. Continued.

- First order decay rate for constituent.
- Temperature correction coefficient for first order decay of constituent.
- Decay rate for constituent adsorbed to suspended sediment.
- Temperature correction coefficient for decay of constituent on suspended sediment.
- Decay rate for constituent adsorbed to bed sediment.
- Temperature correction coefficient for decay of constituent on bed sediment.
- Partition coefficient - distribution coefficients for constituent with: suspended sand, suspended silt, suspended clay, bed sand, bed silt, bed clay.
- Transfer rate between adsorbed and desorbed states for constituent with: suspended sand, suspended silt, suspended clay, bed sand, bed silt, bed clay.
- Temperature correction coefficients for adsorbtion-desorbtion on: suspended sand, suspended silt, suspended clay, bed sand, bed silt, bed clay.
- Initial concentration of constituent on: suspended sand, suspended silt, suspended clay, bed sand, bed silt, bed clay.
- Initial values for water temperature, pH, free radical oxygen concnetration, cloud cover, and total suspended sediment concentration.
- Phytoplankton concentration (as biomass).
- Monthly values of water temperature, pH, and free radical oxygen.
- Base adsorption coefficients for 18 wavelengths of light passing through clear water.
- Increments to base absorbance coefficient for light passing through sediment-laden water.
- Increments to the base absorption coefficient for light passing through plankton-laden water.
- Light extenction efficiency of cloud cover for each of 18 wavelengths.
- Monthly values of average cloud cover.
- Monthly average suspended sediment concentration values.
- Monthly values of phytoplankton concentration.

(7) Inputs to simulate behavior of constituents involved in biochemical transformations.

- Velocity above which effects of scouring on benthal release rates is considered.

(a) Inputs to simulate primary DO, BOD balances.

- Unit BOD decay at 20 °C.
- Temperature correction coefficient for BOD decay.
- Rate of BOD settling.
- Allowable dissolved oxygen supersaturation.
- RCHRES elevation above sea level.
- Benthal oxygen demand at 20°C.

Table A-1. Continued.

- Temperature correction coefficient for benthal oxygen demand.
- Benthal release of BOD at high oxygen concentration.
- Increment to benthal release of BOD under anaerobic conditions.
- A correction factor in the lake reaeration equation to account for good or poor circulation characteristics.
- Empirical constant in Tsivoglou's equation for reaeration.
- Temperature coefficient for surface gas invasion.
- Length of the RCHRES.
- Energy drop over its length.
- Temperature correction coefficient for surface gas invasion.
- Empirical constnat for equation used to calculate reaeration coefficient.
- Exponent to depth used in calculation of reaeration coefficient.
- Exponent to velocity used in calculation of reaeration coefficient.
- Dissolved oxygen.
- Biochemical oxygen demand.
- Dissolved oxygen saturation concentration.

(b) Inputs to determine primary inorganic nitrogen and phosphorous balances.

- Benthal release of inorganic nitrogen, and orthophosphate.
- Concentration of dissolved oxygen below which anerobic conditions exist.
- Unit oxidation rate of ammonia and nitrite at 20°C.
- Initial concentration of nitrate (as N), ammonia (as N), and nitrite (as N).
- Concentration of ortho-phosphorus (as phosphorus).
- Concentration of denitrifying bacteria.

(c) Inputs to simulate behavior of plankton populations and associated reactions.

- Ratio of chlorophyll "A" content of biomass to phosphorus content.
- Nonrefractory fraction of algae and zooplankton biomass.
- Fraction of nitrogen requirements for phytoplankton growth satisfied by nitrate.
- Base extinction coefficient for light.
- Maximal unit algal growth rate.
- Michaelis-Menten constant for light limited growth.
- Nitrate Michaelis-Menten constant for nigrogen limited growth.
- Nitrate Michaelis-Menten constant for phosphorus limited growth.
- Phosphate Michaelis-Menten constant for phosphorus limited growth.

Table A-1. Continued.

- Temperatures above and below which algal growth ceases.
- Temperature below which algal growth is retarded.
- Algal unit respiration rate at 20°C.
- High algal unit death rate.
- Low algal unit death rate.
- Inorganic nitrogen concentration below which high algal death rate occurs (as phosphorus).
- Minimum concentration of plankton not subject to advection (SEED).
- Concentration of plankton not subject to advection at very low flow (MISTAY).
- Outflow at which concentration of plankton not subject to advection is midway between SEED and MXSTAY.
- Chlorophyll "A" concentration above which high algal death rate occurs.
- Rate of phytoplankton settling.
- Rate of settling for dead refractory organics.
- Maximum zooplankton filtering rate at 20°C.
- Zooplankton filtering rate at 20°C (MZOEAT).
- Natural zooplankton unit death rate.
- Increment to unit zooplankton death rate due to anaerobic conditions.
- Temperature correction coefficient for filtering.
- Temperature correction coefficient for respiration.
- The fraction of nonrefractory zooplankton excretion which is immediately decomposed when ingestion rate is greater than MZOEAT.
- Average weight of a zooplankton organism.
- Maximum benthic algae density (as biomass).
- Ratio of benthic algal to phytoplankton respiration rate.
- Ratio of benthic algal to phytoplankton growth rate.
- Initial conditions for phystoplankton (as iomass), zcoplankton algae (as biomass), benthic algae (as biomass), dead refractory organic nitrogen, dead refractory organic phosphorus, and dead refractory organic carbon.

(d) Inputs to simulate pH and carbon species.

- Ratio of carbon dioxide invasion rate to oxygen reaeration rate.
- Benthal release of CO2 (as C) for aerobic and anaerobic conditions.
- Initial total inorganic carbon for pH simulation.
- Initial carbon dioxide (as C) for pH simulation.
- Initial pH.

Appendix B

Preliminary Evaluation of the Nonpoint Source Runoff Model
Agricultural Nonpoint Source Model (AGNPS)

Characteristic	Summary Information
Source	-Model was developed by the U.S. Department of Agriculture - Agricultural Research Service (USDA-ARS) in cooperation with the Minnesota Pollution Control Agency and the Soil Conservation service (SCS) (Young et al., 1987).
Applicable Land Drainage Area	-Agriculture, Forest/Natural
Inputs	-Watershed input: Cell Area (acres) Number of cells Precipitation (total single storm event rainfall in inches) Energy-Intensity value of the storm (USLE) -Cell Parameters: cell number receiving cell number SCS curve number land slope (percent) slope shape factor field slope length channel slope (percent) channel sideslope (percent) Manning's roughness coefficient for the channel soil erodibility factor cover and management factor support practice factor surface condition constant aspect soil texture fertilization level fertilizer availability factor point source indicator

Preliminary Evaluation of the Nonpoint Source Runoff Model

Agricultural Nonpoint Source Model (AGNPS)

Inputs (cont.)	-Cell Parameters (cont.): gully source level (tons) chemical oxygen demand (COD) factor impoundment factor channel indicator -For a complete explanation of AGNPS inputs see Table B-1.
Outputs	-Hydrology Output: Runoff volume (inches) Peak runoff rate (cubic ft/s) Fraction of runoff generated within cell -Sediment Output: Sediment yield (tons) Sediment concentration (ppm) Sediment particle size distribution Upland erosion (tons/acre) Amount of deposition (%) Sediment generated within cell (tons) Enrichment ratios by particle size Delivery ratios by particle size -Chemical Output Nitrogen and Phosphorus Sediment associated mass (lbs/acre) Concentration of soluble material (ppm) Mass of soluble material (lbs/acre) Chemical Oxygen Demand Concentration (ppm) Mass (lbs/acre)
Comments	-AGNPS is a distributed parameter model; watershed size range

Appendix B Continued

Preliminary Evaluation of the Nonpoint Source Runoff Model

Agricultural Nonpoint Source Model (AGNPS)

Comments (cont.)

2.5-23,000 acres, subdivided into 1 acre cells; a cell is the smallest unit in which analysis can be performed. Figure B-1. shows an example of the numbering system used to identify cells and the drainage patterns in the cells.

-AGNPS is a single storm event model based in part on the Universal Soil Loss Equation (USLE).

-AGNPS is a microcomputer based simulation model designed to provide the water resource manager a means of objectively evaluating nonpoint source pollution from agricultural watersheds (Bill and Bartholic, 1988).

-The model was designed to meet the following objectives: to obtain uniform and accurate estimates of runoff quality with an emphasis on nutrients and sediment; to compare the effects that various management practices have on runoff quality; and to develop a flexible and user-friendly model (Bill and Bartholic, 1988).

-Developed and tested in Minnesota only.

-Limited testing of pollutants runoff functions.

-Single event simulation of runoff quantity from agricultural watersheds; BMP evaluation.

Preliminary Evaluation of the Nonpoint Source Runoff Model

Agricultural Nonpoint Source Model (AGNPS)

Comments (cont.)

-PC versions of AGNPS are written in Microsoft Fortran with a user-friendly shell.

-The current version of AGNPS is Version 3.5, a larger and more powerful computer than prior versions of the AGNPS model. Because of this fact, the minimum computer hardware to AGNPS is as follows:

IBM PC
640 KB RAM
DOS 3.0 or greater
3 MB free on Hard Disk
CGA minimum monitor

Math coprocessors are highly recommended for speed of execution

-AGNPS simulates runoff volume for each cell using the USDA SCS (1972) curve number method, but does require Manning's roughness coefficient for the channel as an input parameter within each cell.

-AGNPS requires a surface condition constant as an input for each cell which is a value based on land use at the time of the storm to make adjustments for the time it takes overland runoff to channelize.

-The method used to predict Nitrogen and Phosphorus yields from the cells and watershed were developed by Frere et al. (1980) and appear in CREAMS.

Table B-1. Complete listing of AGNPS input structure.

CELL PARAMETERS

Cell number: The identification number assigned to each cell in the watershed. Cells are numbered consecutively beginning at the cell in the northwest corner and proceeding west to east, north to south (Figure 3).

Receiving cell number: The number of the cell into which the most significant portion of the runoff drains. Drainage direction is determined by cell topography (Source: Bronson North USGS 7 1/2 minute topographic quadrangle).

Soil Conservation Service (SCS) runoff curve number: The runoff curve number or hydrologic soil-cover complex number used in the SCS's equation for estimating direct runoff from storm runoff. (Source: table in user documentation; Young, 1986).

Land Slope: The major slope, in percent, of the cell. (Source: Bronson North USGS 7 1/2 minute topographic quadrangle; table in the Branch County Soil Survey USDA-SCS, 1986).

Slope Shape Factor: An identification number used to indicate the dominant slope shape of the cell. One-uniform slope, two-convex slope, three-concave slope. (Source: visual inspection).

Field Slope Length: The length of the dominant field in the cell. Field slope length is measured from the top of the slope to the bottom of the slope where deposition occurs. (Source: measurements and visual inspection by the watershed coordinator of the Branch County Soil Conservation District).

Channel Slope: The average slope or grade, in percent, of the channel or channels in the cell (Source: USGS Bronson North topographic quadrangle).

Channel Sideslope: The average slope of the channel bank, in percent. (Source: maps and measurements from the office of the Branch County Drain Commissioner).

Manning's Roughness Coefficient: Roughness coefficients representing

Table B-1. Continued.

vegetation along the channel. (Source: table in the user documentation; Young, 1986).

Soil erodibility factor: The parameter used in the Universal Soil Loss Equation. (Source: Branch County Soil Survey USDA- SCS, 1986).

Cropping factor: The crop and cover factor used in the Universal Soil Loss Equation. The value selected for each cell must correspond to the growth of the crop at the time of the storm. Cropping factors do not exist for storm events; therefore the authors used values corresponding to cropstage periods. To represent the worst case or the time of the year when the soil is most vulnerable to erosion, cropping factors corresponding to a fallow period were used. (Source: Agricultural Handbook Number 537; USDA, 1978).

Practice factor: The factor used in the Universal Soil Loss Equation to indicate the presence of contour cropping, contour strip cropping and/or impoundment terrace. (Source: visual inspection).

Surface condition constant: A value based on land use at the time of the storm to make adjustments for the time it takes overland runoff to channelize. (Source: table in user documentation; Young, 1986).

Aspect: A single digit indicating the principle direction of drainage from the cell. Eight possible directions are possible, 1 being north and proceeding clockwise, 8 being northwest. (Source: Bronson North USGS 7 1/2 minute topographic quadrangle, visual inspection).

Soil Texture: The major soil texture classification for the cell. Five texture classes are possible: water, sand, silt, clay, peat. (Source: Branch County Soil Survey; USDA, 1986). **Fertilization Level:** A single digit indicating the level of nitrogen and phosphorus fertilization on the field. (Source: the watershed coordinator).

Fertilizer Availability Factor: The percent fertilizer left in the top half inch of the soil at the time of the storm. The factor is based on the tillage practices used to incorporate fertilizer into the soil. The worst case would be if none of the fertilizer had been incorporated into the soil at the time of the storm and would have a factor of 100%. Availability factors, listed according to tillage practice used to incorporate the fertilizer, are included in a table in the user documentation. In Branch County, fertilizer is commonly injected with the seed at the time of planting. This technique places the fertilizer well below the top 1/2 inch of the soil, reducing the fertilizer runoff potential. This technique was not represented in the user documentation; therefore, an availability factor of 3 was assigned to represent this fertilizer practice. (Source: table in the user documentation; Young, 1986).

Point Source Indicator: A single-digit indicator of the number of feedlots in a cell. If feedlots are indicated, additional information is required, including the acreage of covered and uncovered areas, curve numbers for exercise and buffer areas, and the number and type of animals. There is one 4 acre feedlot near the headwaters of the watershed. It lies in a cell immediately adjacent to the channel. There is a break in the protective berm and effluent discharges into the channel during storms. It is not presently in operation; however, manure has settled in the stream. Feedlot parameters were input into the model to simulate past problems and effects on water quality if the feedlot were to return to operation without repair. (Source: the watershed coordinator).

Gully Source Level: An estimate of the tons of gully erosion occurring in the cell. The model will incorporate this estimate into the total amount of sediment eroded in the cell. No gully source level was estimated in the Little Swan Creek Watershed.

Chemical Oxygen Demand (COD) factor: The value for the COD concentration from the cell, based on land use in the cell. (Source: table in the user documentation; Young, 1986).

Impoundment factor: A factor indicating the presence of an impoundment terrace system within the cell. If the presence of impoundment(s) is indicated, additional information is required. No impoundment terraces are present in the watershed.

Appendix C

Preliminary Evaluation of the Nonpoint Source Runoff Model **Areal Nonpoint Source Watershed Environmental Response Simulation (ANSWERS)**

Characteristic	Summary Information
Source	-The model is maintained and is provided by the Department of Agricultural Engineering, Purdue University, West Lafayette, Indiana (Beasley, 1977; Beasley et al., 1980). -Also avaialble from the EPA, EPA-905/9-82-001. (Beasley and Huggins, 1982).
Applicable Land Drainage Area	-Agriculture, Forest/Natural
Inputs	-Simulation Requirements: Measurement units Output control -Rainfall Information Times Intensities -Soils Information Total porosity (% volume) Field capacity (% saturation) Steady state infiltration rate Difference between steady state and maximum infiltration rate Exponent in infiltration equation Antecedent soil moisture (% saturation) USLE "K" Tile drainage coefficient Groundwater release fraction -Land Use and Surface Information Specific land use and management Potential interception volume Percentage of surface covered by specific land use (crop) Roughness coefficient (a shape factor)

Appendix C Continued

Preliminary Evaluation of the Nonpoint Source Runoff Model **Areal Nonpoint Source Watershed Environmental Response Simulation (ANSWERS)**

Inputs (cont.)	-Land Use and Surface Information (cont.) Maximum roughness height Manning's n Relative erosiveness of a particular landuse (function of time and USLE "C" and "P" -Channel Descriptions width roughness -Individual Element Information slope steepness (%) direction of steepest slope (degrees) channel size soil type number crop/management type number channel slope steepness BMP identification number mean elevation
Outputs	-The output listing consists of five basic sections: 1) An echo of the input data (optional) 2) Watershed characteristics 3) Flow and sediment information at the watershed outlet and effectiveness of structural BMPs. flow hydrograph sediment concentration accumulative yield total rainfall total flow average sediment yield BMP performance 4) Net transported sediment field or deposition for each element. actual amount deposited on or removed from each element or cell 5) Channel deposition

Appendix C Continued

Preliminary Evaluation of the Nonpoint Source Runoff Model **Areal Nonpoint Source Watershed Environmental Response Simulation (ANSWERS)**

Comments	-It is a distributed parameter model, and consequently a watershed must first be subdivided into a grid of square elements as shown in Figure B-1. -ANSWERS is primarily event oriented (Novotny, 1986). -ANSWERS is a model that simulates behavior of watersheds having agriculture as their primary land use (Novotny, 1986). -Sediment detachment is computed by modified version of the Universal Soil Loss Equation. Land use changes, tillage techniques and management procedures for controlling nonpoint source pollution are simulated with ANSWERS by using appropriate values. At this moment only water and sediment yields from watersheds can be modelled by the public version of the model. The ANSWERS model does not require extensive calibration (Novotny, 1986). -ANSWERS was designed as a planning tool for persons concerned with nonpoint source pollution originating on agricultural lands. Recent work has been aimed at the extension of the application areas to disturbed soil situations, e.g., construction sites, surface mine reclamation, etc (Beasley, 1986).

Appendix C Continued

Preliminary Evaluation of the Nonpoint Source Runoff Model
Areal Nonpoint Source Watershed Environmental Response Simulation (ANSWERS)

Comments (cont.)	-Extensively validated for the midwest (IEP, 1990).
	-Has been used primarily for analysis of single sites (IEP, 1990).
	-Modular program is easily modified (IEP, 1990).
	-Considers sediment and erosion control only, no other water quality considerations (IEP, 1990).
	-Single event simulation of hydrology and sediment generation from agricultural watershed; BMP evaluation (IEP, 1990).
	-ANSWERS model estimates runoff, erosion, and sediment transport from basin-sized areas. It has been used to identify sources of erosion and areas of deposition within the basin (Leonard and Knisel, 1986).
	-Chemicals associated with eroded sediment are, in the current version of the model, predicted by correlation relationships between chemical concentrations and sediment yeilds (Beasely, 1986).

Appendix D

Preliminary Evaluation of the Nonpoint Source Runoff Model **Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS)**

Characteristic	Summary Information
Source	-USDA model (Knisel,1980), available from USDA Science and Education Department, Tifton, Georgia. -User's guide available from SCS, 1984. (Tech. Release 72).
Applicable Land Drainage Area	-Field-Size Agricultural
Inputs	-Precipitation: Option 1: Daily rainfall for yearly periods Option 2: Hourly rainfall for single storm rain event. -Hydrology Component (only) Both options: Field area (acres) Saturated hydraulic conductivity (in/hr) Fraction of storage filled at the field capacity for the effective root zone Average monthly temperature (°F) Average net monthly radiation (langleys/day) Winter cover factor Leaf area index Option 1: Initial abstraction (CN method) SCS curve number Channel slope Watershed length/width ratio Depth of root zone Fraction of plant available water content to start irrigation

Appendix D Continued

Preliminary Evaluation of
the Nonpoint Source Runoff Model
Chemicals, Runoff, and Erosion
from Agricultural Management Systems (CREAMS)

Inputs (cont.)	-Hydrology Component (only) Option 1: (cont.) Fraction of plant available water content to start irrigation Upper limit of storage of plant-available and drainage water for each layer of the 7 layers in the root zone (in) Option 2: Depth of surface soil Effective capillary tension Manning roughness for feild surface Average field slope Length of flow plane -Erosion/Sedimentation Component (parameters not listed) -Chemistry Component (parameters not listed) -For a complete list of the input parameters required to run all three components of the CREAMS model with their respective explanations and suggested sources of development, refer to the CREAMS User's Guide (SCS, 1984).
Outputs	-Combinations of the following three time simulations are available for each model component: Annual summary output Storm-by-storm output Monthly output -Hydrology Component Estimations: Runoff volume (cm) Peak runoff rates (cm) Percolation from the plant root zone (cm)

Appendix D Continued

Preliminary Evaluation of the Nonpoint Source Runoff Model **Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS)**

Outputs (cont.)	-Hydrology Component Estimations: (cont.) Soil water content (cm) evapotranspiration (cm) infiltration (cm) -Erosion/Sedimentation Component Estimations: Sediment yield (kg/ha) Particle Size distribution -Chemistry Component Estimations: Nutrients (Nitrogen, Phosphorus) loadings (kg/ha) in runoff concentrations (ppm) in runoff Pesticides loadings (kg/ha) in runoff concentration (ppm) in runoff Average concentrations of adsorbed and dissolved chemicals in the runoff, sediment, and percolate fractions are estimated.
Comments	-CREAMS is a lumped parameter model consisting of three major components: (1) hydrology, (2) erosion/sedimentation, (3) chemistry. -The hydrology component has two options, depending upon availability of rainfall data. Option one estimates storm runoff when only daily rainfall data is available using the SCS curve number method. When hourly rainfall data is available, option two estimates runoff by the Green-Ampt Equation (Novotny, 1986). Peak runoff rates are estimated using kinematic flow equations solved by the method of characteristics (Ewing, 1989).

Appendix D Continued

Preliminary Evaluation of the Nonpoint Source Runoff Model
Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS)

Comments (cont.)	-The erosion/sedimentation component utilizes the results of the hydrology component to compute erosion and sedimentation for overland flow, channel flow, and impoundments (Ewing, 1989). The erosion component considers the basic processes of soil detachment transport, and deposition. Erosion from the overland elements is computed using the modified Universal Soil Loss Equation for a single storm event (Novotny, 1986). A detachment relationship based on the shear stress stress of channel flow is used to compute channel erosion. The concept of the model presumes that sediment load is controlled by the losses of transport capacity or by the amount of sediment available for transport (Knisel, 1980). The Yalin sediment transport equation (Yalin, 1963) is used to compute the sediment transport capacity of runoff. Sedimentation is computed according to the fall velocity of sediment particle sizes. An accounting procedure is used to determine the sources of sediment that fill the transport capacity of the flow. Sediment movement is routed using a continuity-of-mass equation (Ewing, 1989). -The basic concepts of the nutrient component are that nitrogen and phosphorus attached to soil particles are lost with the sediment yield, soluble nitrogen and phosphorus are lost

Appendix D Continued

Preliminary Evaluation of the Nonpoint Source Runoff Model **Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS)**

Comments (cont.)	with surface runoff and soil nitrate is lost by leaching with percolation, by denitrification or by plant uptake (Novotny, 1986). The pesticide component estimates concentrations of pesticides in runoff (water and sediment) and total mass carried from the field for each storm during the period of interest. Pesticide ruoff is partitioned between the solution and the solution and the sediment phase using a simplified linear isotherm model (Novotny, 1986). -Surface runoff only; no sub-surface functions. -CREAMS requires parameter values which only represent a single crop being grown in the watershed during each year; however, the crop can vary from year to year (Ewing, 1989). -The CREAMS model predicts the delivery of runoff, sediment, pesticides, and nutrients from a drainage area within a field. A field is a management unit having (1) a single land use, (2) relatively homogeneous soils, (3) spatially uniform rainfall, (4) a single management system. Normally, a field is less than 100 acres (SCS, 1984).

Appendix D Continued

Preliminary Evaluation of the Nonpoint Source Runoff Model **Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS)**

Comments (cont.)	-The model was developed with four objectives in mind: (1) to be physically based, thereby **not** requiring calibration for specific applications; (2) to be simple and easy to use while remaining a fairly accurate representation of the physical system; (3) to be capable of estimating annual values of runoff, percolation, erosion, and dissolved and adsorbed plant nutrients and pesticide losses; and (4) to be able to distinguish between different agricultural management practices (Ewing, 1989). -CREAMS has been extensively tested with various conclusions (Ewing, 1989; Jamieson and Clausen, 1989; Leonard and Knisel, 1986; Heatwole et al., 1988)

Appendix E

Preliminary Evaluation of the Nonpoint Source Runoff Model

Nonpoint Source Model (NPS)

Characteristic	Summary Information
Source	-EPA: 600/3-77-065 NTIS PB-250 566 Donigian and Crawford, 1977
Applicable Land Drainage Area	-Urban, Agriculture
Inputs	-Precipitation, temp., evapotranspiration, infiltration, watershed area, land use information--fraction of watershed in each land use, hydrogeometric data (Manning's n, slope, length), water quality data.
Outputs	-Summary of simulation run characteristics and input parameters, time interval output and storm summaries--user can specify minimum "trigger" flow to produce output when exceeded, monthly and yearly summaries for total run-runoff, peak flow, total residual washoff, maximum residuals mass washoff, mean residuals concentrations, maximum residuals concentration during storm events.
Comments	-NPS is currently incorporated in the HSPF model and is no longer available as a separate entity. -NPS is a lumped parameter model -Event loads or continuous simulation. -NPS only handles constituent transport when linked to sediment transport.

Appendix E Continued

Preliminary Evaluation of the Nonpoint Source Runoff Model

Nonpoint Source Model (NPS)

Comments (cont.)	-Model hydrology derived from Stanford Watershed Model and HSP-QUALITY. -NPS developed by Hydrocomp, Inc., for EPA Environmental Research Lab., Athens GA. -Erosion processes simulated with Universal Soil Loss Equation. -NPS simulations represent adsorbed constituents relatively well, but lack the ability to simulate accurately constituents which are transported totally or partially in the aqueous phase. -NPS documentational reports available from NTIS for nominal cost, or from EPA Southeast Environmental Research Lab., Athens, Ga. or Hydrocomp, Inc., Palo Alto, Ca. -Documentation includes a brief theoretical description of model and subroutines, individual parameter evaluations, sample model input, descriptive calibration information, source listing. -An EPA model (Donigian and Crawford, 1977). -Coded in Fortran IV. -Quality constituents represented: BOD, sat DO, 5 user-specified sediment attached constituents.

Appendix F

Preliminary Evaluation of the Nonpoint Source Runoff Model **Generalized Watershed Loading Functions (GWLF)**

Characteristic	Summary Information
Source	-Prof D. Haith, Cornell University 308 Riley-Robb Hall Ithaca, NY 14850
Applicable Land Drainage Area	-Urban, Agriculture Forest/Natural
Inputs	-The input structure is broken up into 3 components as follows: -Transport component: Land use type Land use area (ha) SCS curve number KLSCP (USLE factor) Monthly evapotranspiration cover coefficient Average monthly daylight hours Growing season indicator Monthly (seasonal) coefficient "a" for the Richardson rainfall erosivity relationship Antecedent rain/melt for previous five days Groundwater parameters: -initial unsaturated storage (cm) -initial saturated storage (cm) -recession coefficient -seepage coefficient Initial snow (cm water) Sediment delivery ratio -Nutrient component: Dissolved concentration of nitrogen and phosphorus (nutrients) runoff from each specified land use (mg/l).

Appendix F Continued

Preliminary Evaluation of the Nonpoint Source Runoff Model **Generalized Watershed Loading Functions (GWLF)**

Inputs (cont.)	-Nutrient component (cont.) Nutrient concentration in runoff from manured areas (mg/l) Nutrient build-up on urban land uses (kg/ha-day) Monthly loads of nutrients from point sources (kg) Nutrient concentration in groundwater (mg/l) Nutrients in sediment (mg/kg) Months of manure spreading -Weather component: The weather file is arranged by months (April - March) 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 (Wu et al., 1989).
Outputs	-Transport information: Monthly precipitation (cm) Evapotranspiration (cm) Groundwater flow (cm) Runoff (cm) Streamflow (cm) -Sediment/Nutrient information: Erosion (1000 tonnes) Sediment (1000 tonnes) Dissolved nitrogen (tonnes) Dissolved phosphorus (tonnes) Total nitrogen (tonnes) Total phosphorus (tonnes) -Land use information: Land use area (ha) Runoff from land use (cm) Erosion from land use (t/ha) Dissolved nitrogen from land use (tonnes)

Appendix F Continued

Preliminary Evaluation of the Nonpoint Source Runoff Model
Generalized Watershed Loading Functions (GWLF)

Outputs (cont.)	Dissolved phosphorus from land use (tonnes) Total nitrogen from land use (tonnes) Total phosphorus from land use (tonnes)
Comments	-The GWLF model describes nonpoint sources with a distributed model for runoff, erosion and urban wash off, and a lumped parameter linear resevoir ground water model. Point sources are added as constant mass loads that are assumed known (Haith and Shoemaker, 1987). -GWLF provides continuous simulation. -Runoff is computed from daily weather data by the U.S. Soil Conservation Service's Curve Number Equation (Ogrosky and Mockus, 1964). -Stream flow nutrient flux contains dissolved and solid phases. GWLF models dissolved nutrients associated with runoff, point sources, and ground water discharges to the stream, and solid phase nutrients due to point sources, rural soil erosion, or wash off of material from urban surfaces (Haith and Shoemaker, 1987). -Model Mechanics: GWLF predicts nutrient loads using a mass balance approach. The algorithms used to determine the individual nutrient loadings of dissolved and solid-phase particles from different source areas are as follows:

Appendix F Continued

Preliminary Evaluation of the Nonpoint Source Runoff Model **Generalized Watershed Loading Functions (GWLF)**

Comments (cont.)	Rural Runoff: Dissolved nutrients = runoff **X** dissolved concentration (field measurements or default). Solid-phase nutrients = monthly sediment yields **X** average sediment nutrient concentration (field measurements or default). Sediment yield = erosion **X** sediment delivery ratio (Vanoni, 1975; yield in any month is proportional to the total transport capacity of daily runoff during the month). Erosion = f(USLE, daily rainfall erosivity index (Richardson et. al., 1983)) Urban Runoff: Dissolved nutrients = 0 (the urban component of GWLF follows the structure of the U.S. Army Corps of Engineers' model STORM which considers nutrient mass to be associated with accumulated solids, thus urban nutrient loads are assumed to be entirley solid-phase). Solid-phase nutrients = 1 - exp(-1.81 Qkt) which describes the fraction of accumulated nutrient mass removed from land use k on day t; Qkt is runoff from land use k on t, in centimeters (Amy et al., 1974) Ground Water Sources: Ground water discharge to the stream is described by a lumped parameter model based on the hydrologic budget of the watershed.

Appendix F Continued

Preliminary Evaluation of the Nonpoint Source Runoff Model

Generalized Watershed Loading Functions (GWLF)

Comments (cont.)	Dissolved nutrients = total monthly groundwater discharge X average nutrient concentration in ground water (field measurements or default). -The simple model structure and data requirements make easily programmed for microcomputer (a basic version for MS-DOS computers is available upon request) (Haith and Shoemaker, 1987).

APPENDIX G

Figure G-1. Hyetograph for Mount Desert Island for the Wet Year (April 1983 through March 1984).

Figure G-2. Hyetograph for Mount Desert Island for the Dry Year (April 1987 through March 1988).

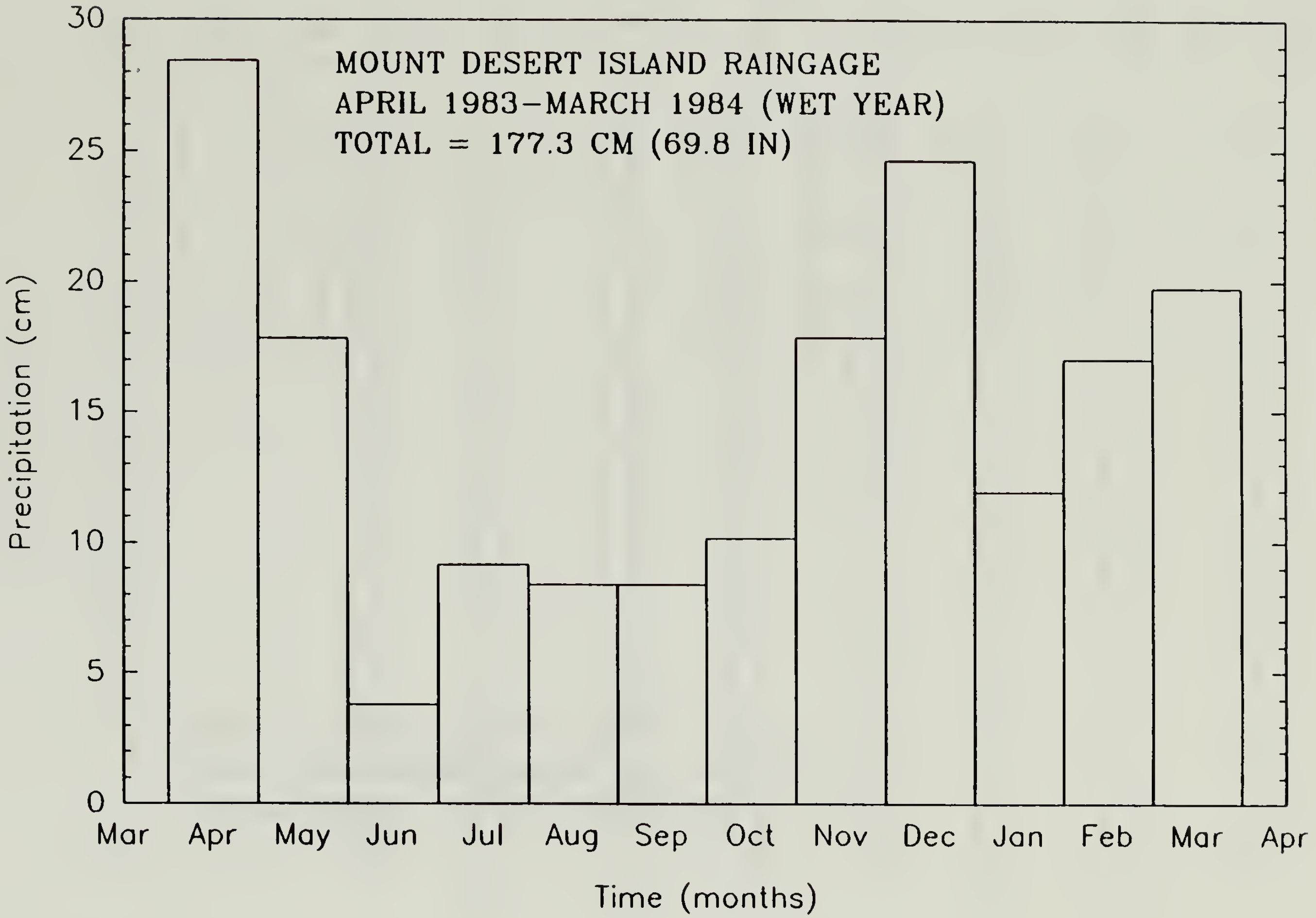

Figure G-1. Hyetograph for Mount Desert Island for the Wet Year (April 1983 through March 1984).

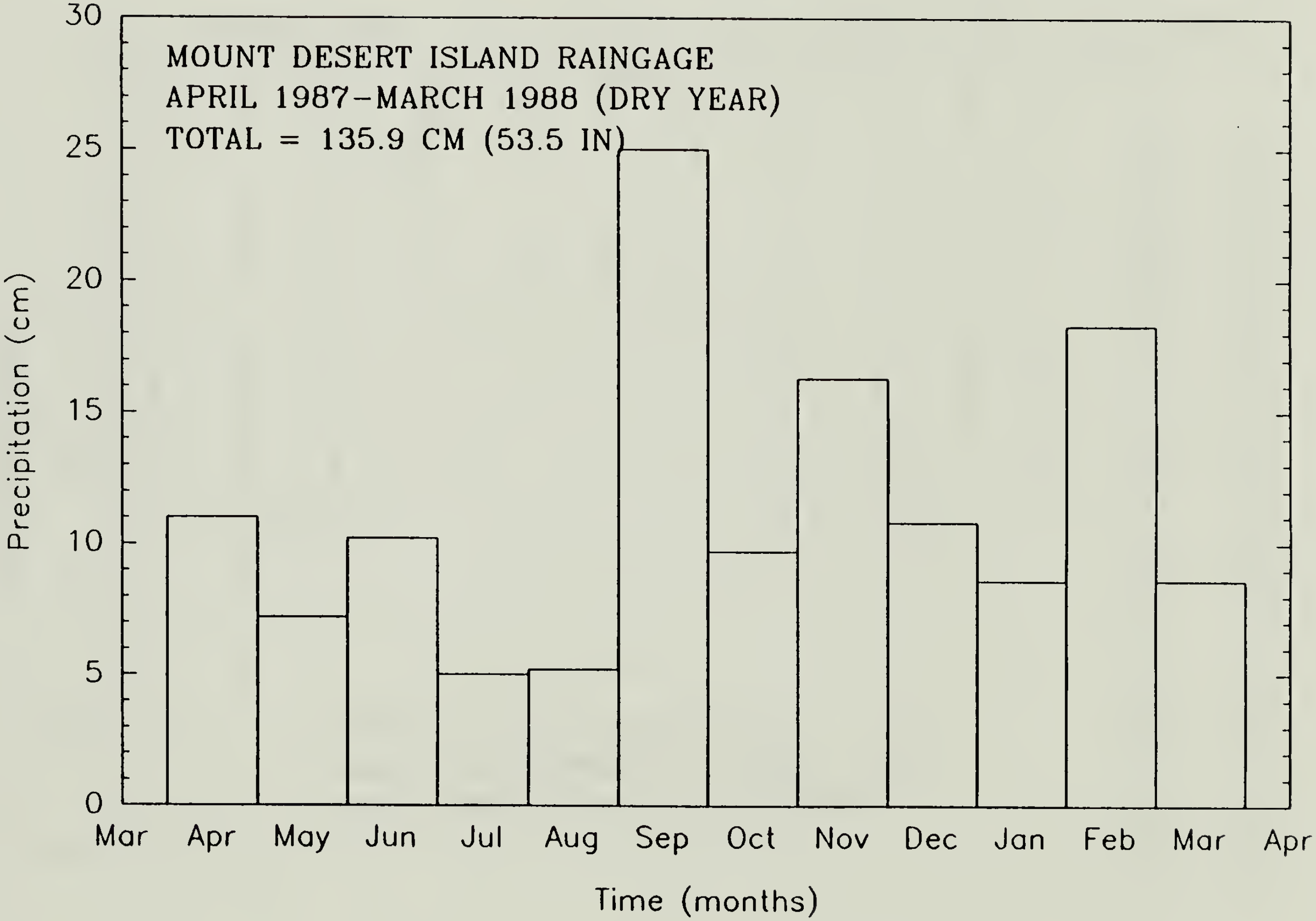

Figure G-2. Hyetograph for Mount Desert Island for the Dry Year (April 1987 through March 1988).

APPENDIX H

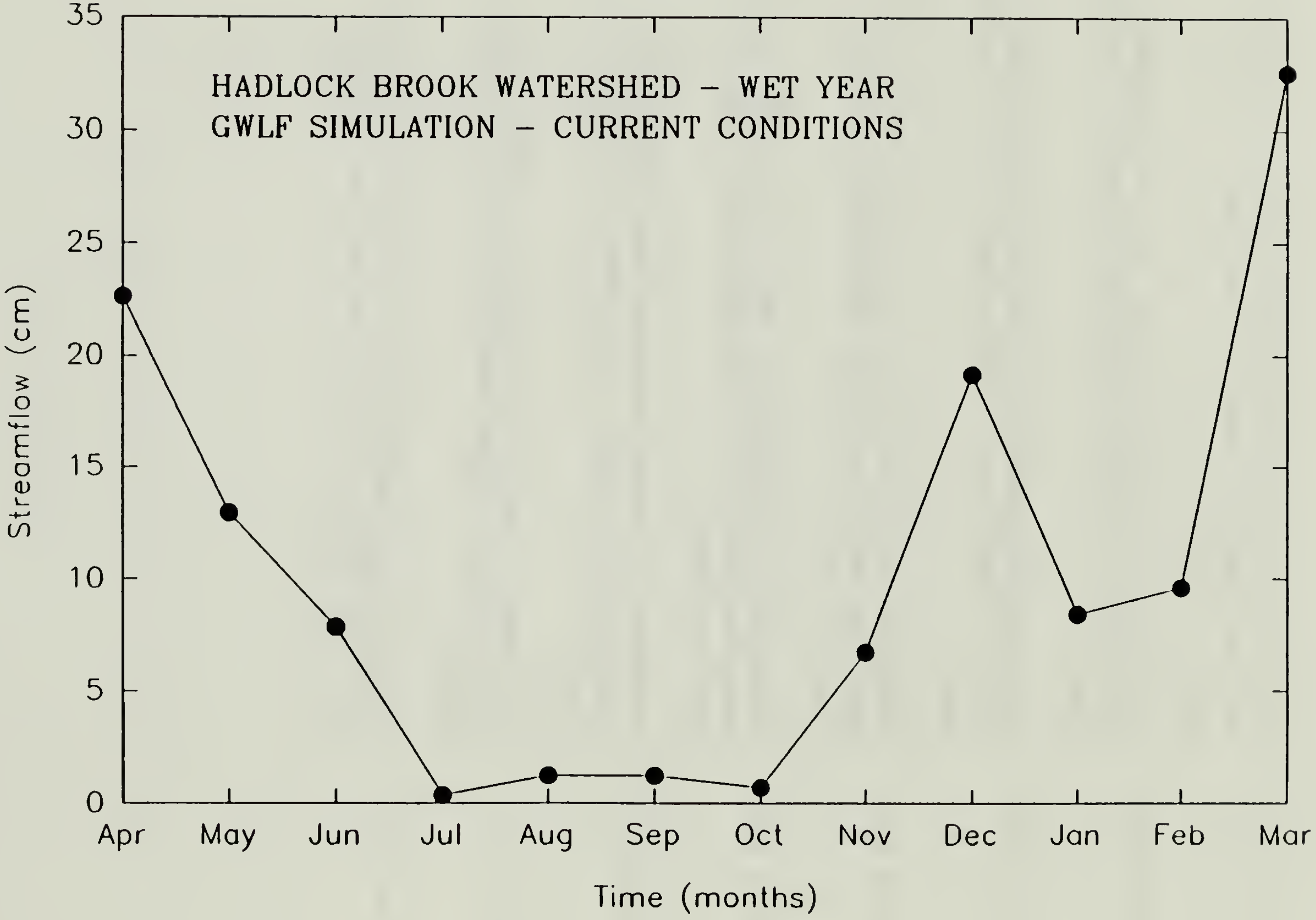

Figure H-1. **Streamflow Simulation from the GWLF Model for the Hadlock Brook Watershed During the Wet Year.**

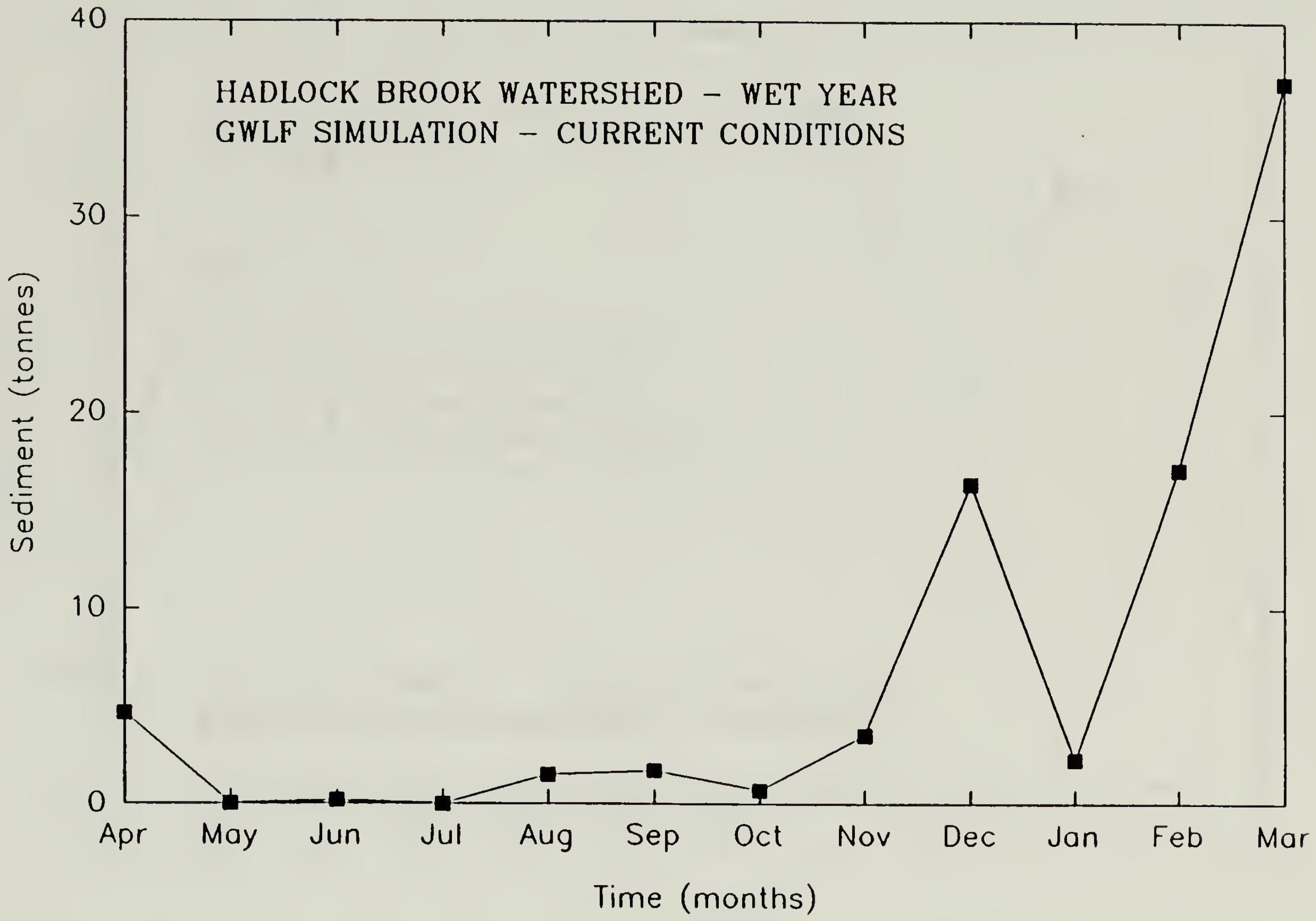

Figure H-2. Sediment Simulation from the GWLF Model for the Hadlock Brook Watershed During the Wet Year.

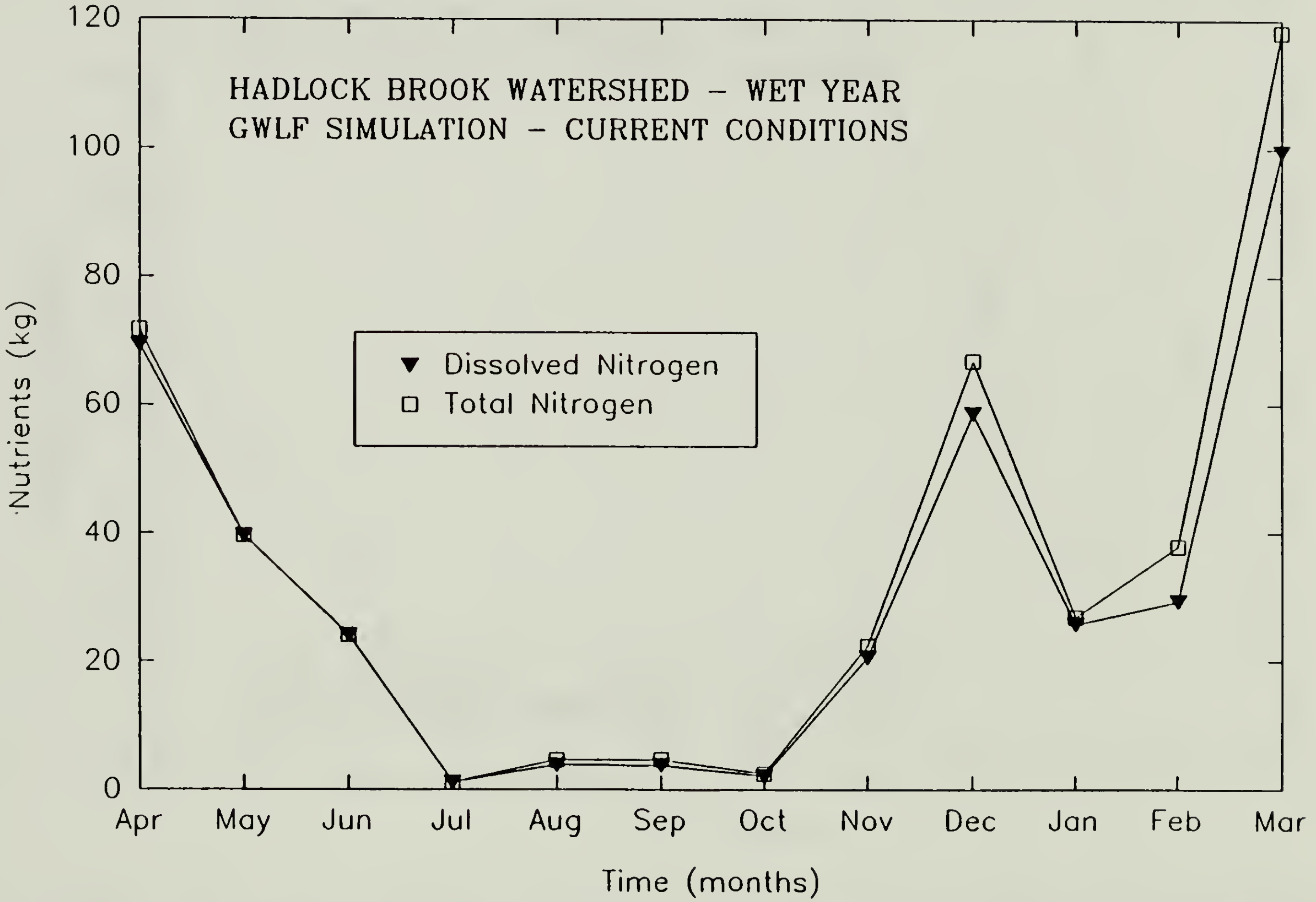

Figure H-3. Nitrogen Simulation from the GWLF Model for the Hadlock Brook Watershed During the Wet Year.

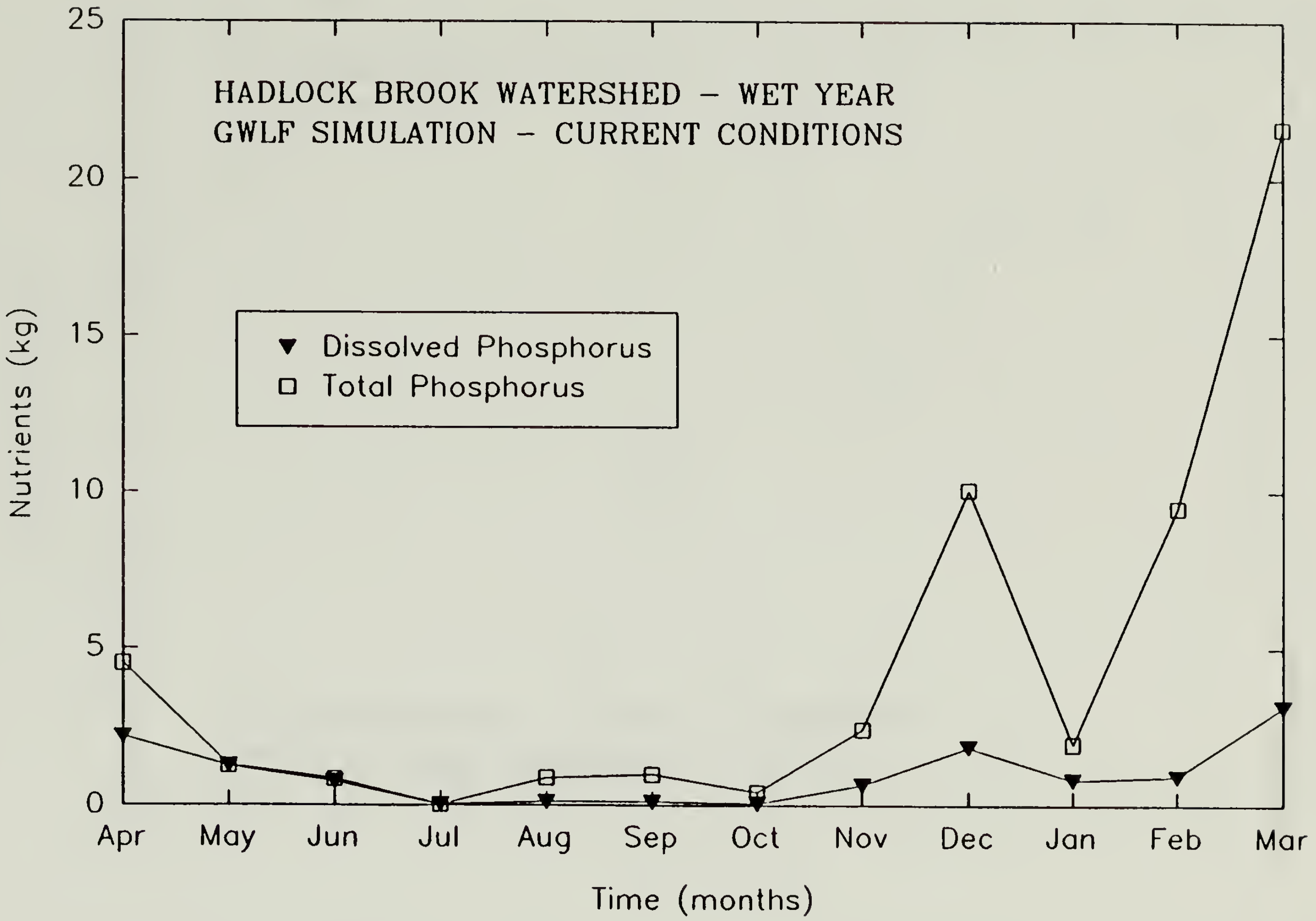

Figure H-4. Phosphorus Simulation from the GWLF Model for the Hadlock Brook Watershed During the Wet Year.

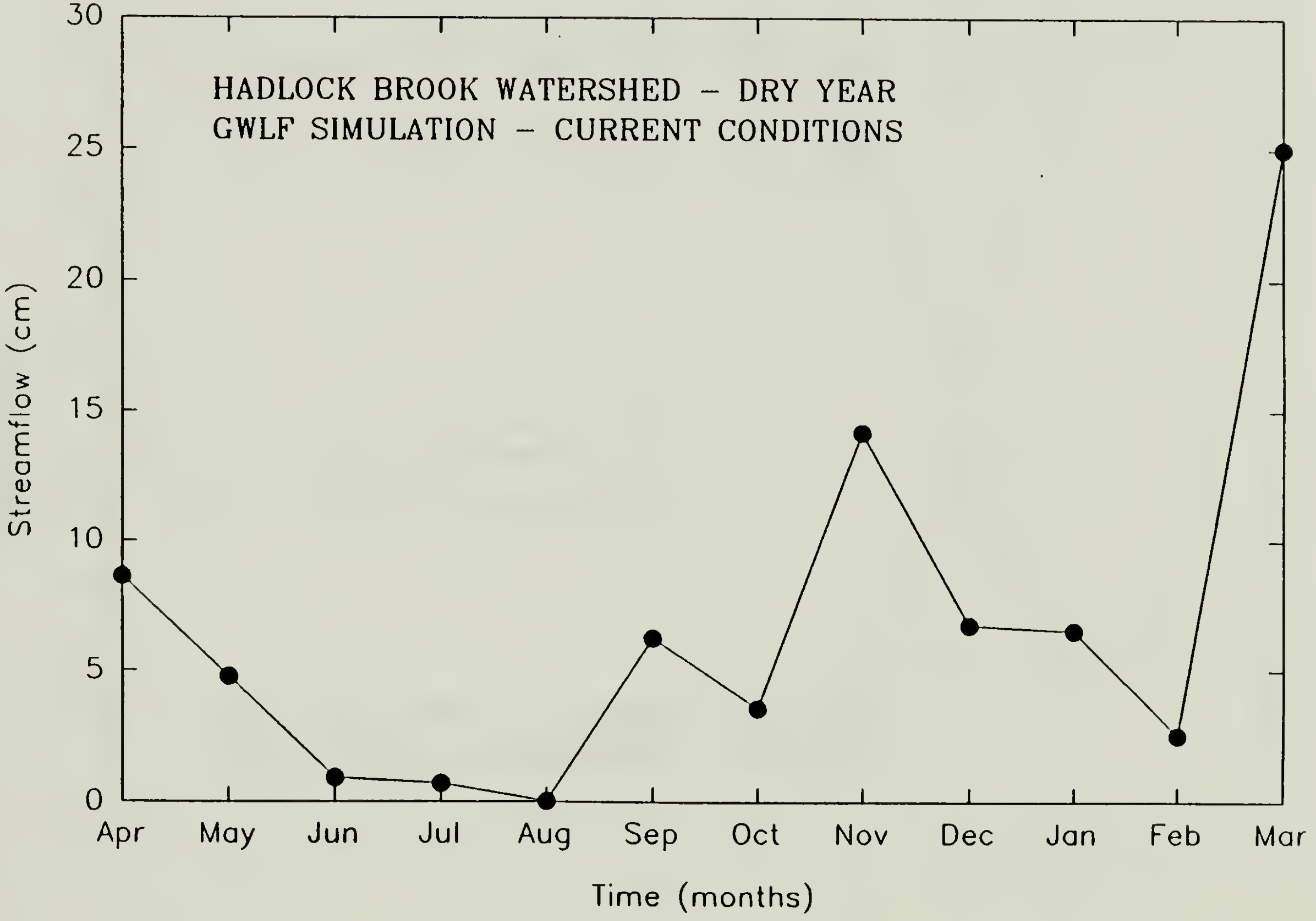

Figure H-5. Streamflow Simulation from the GWLF Model for the Hadlock Brook Watershed During the Dry Year.

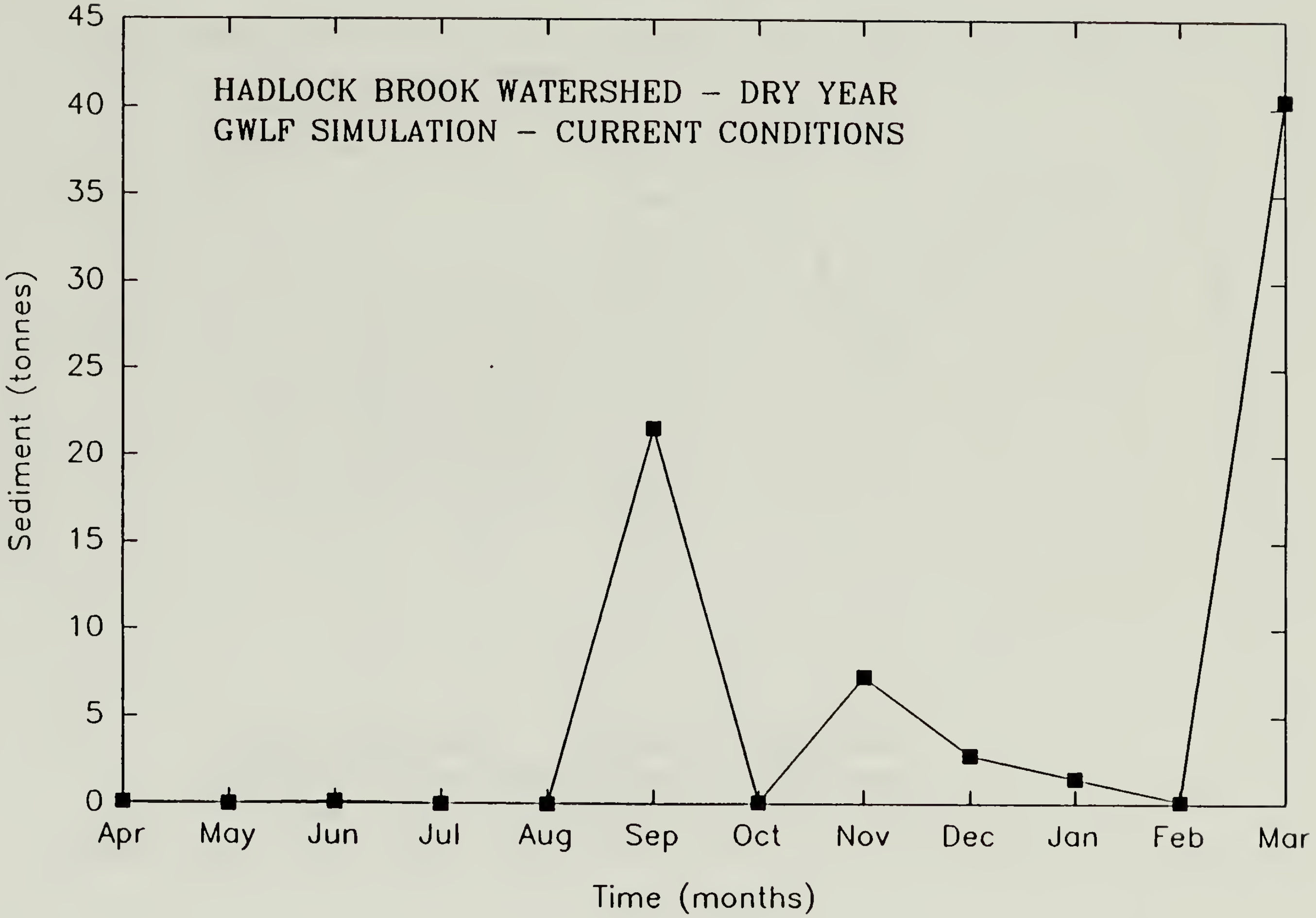

Figure H-6. Sediment Simulation from the GWLF Model for the Hadlock Brook Watershed During the Dry Year.

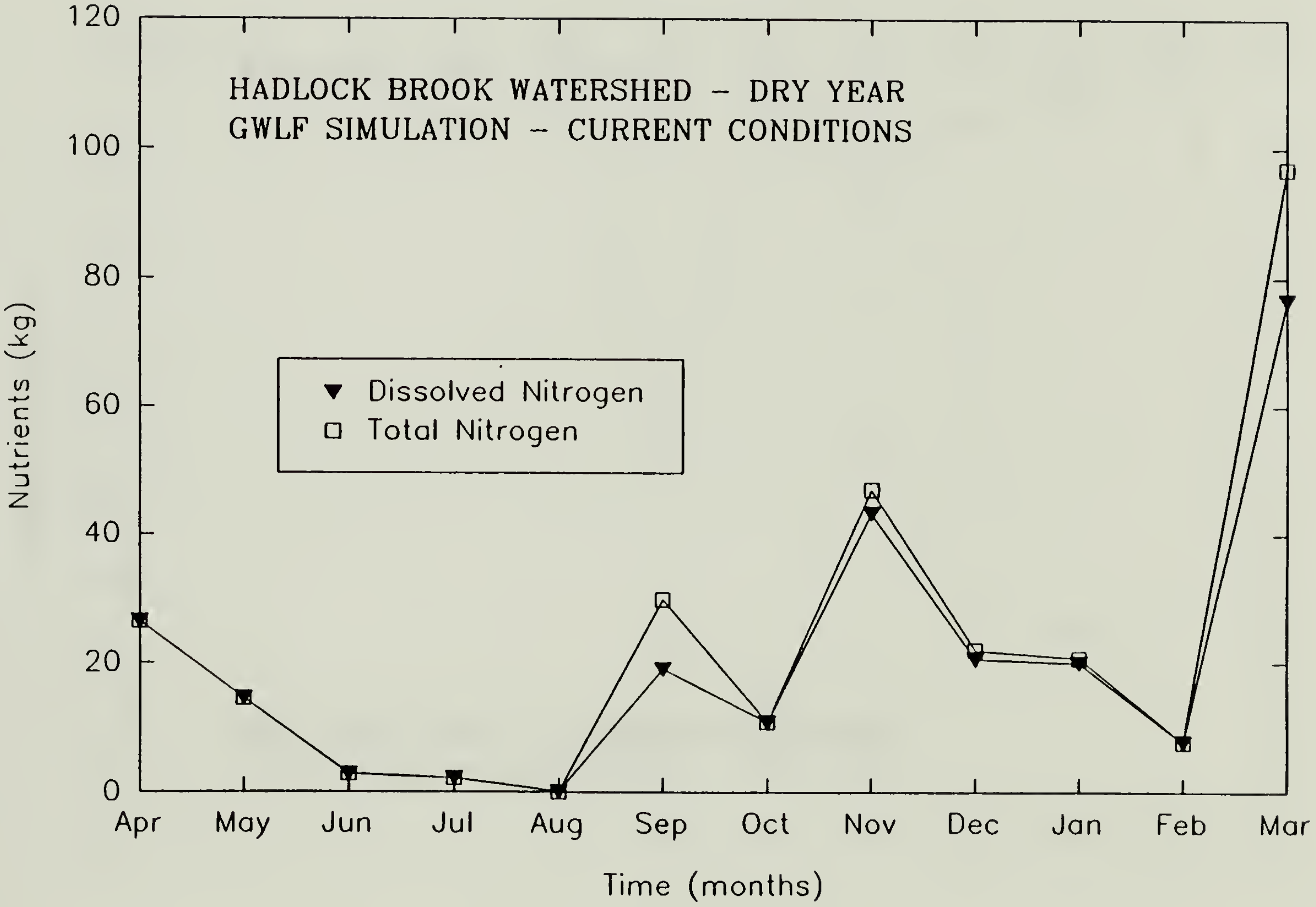

Figure H-7. Nitrogen Simulation from the GWLF Model for the Hadlock Brook Watershed During the Dry Year.

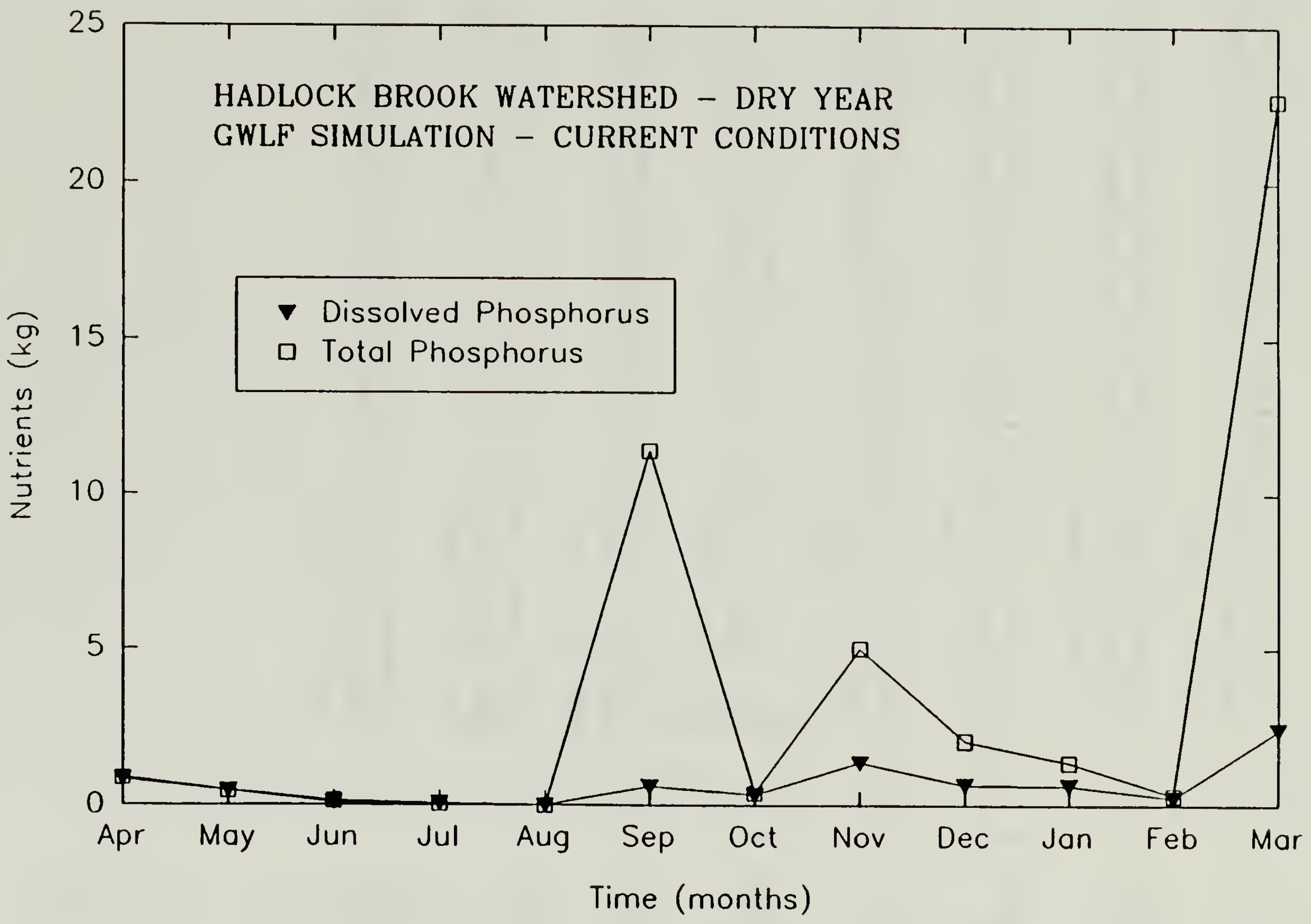

Figure H-8. Phosphorus Simulation from the GWLF Model for the Hadlock Brook Watershed During the Dry Year.

APPENDIX I

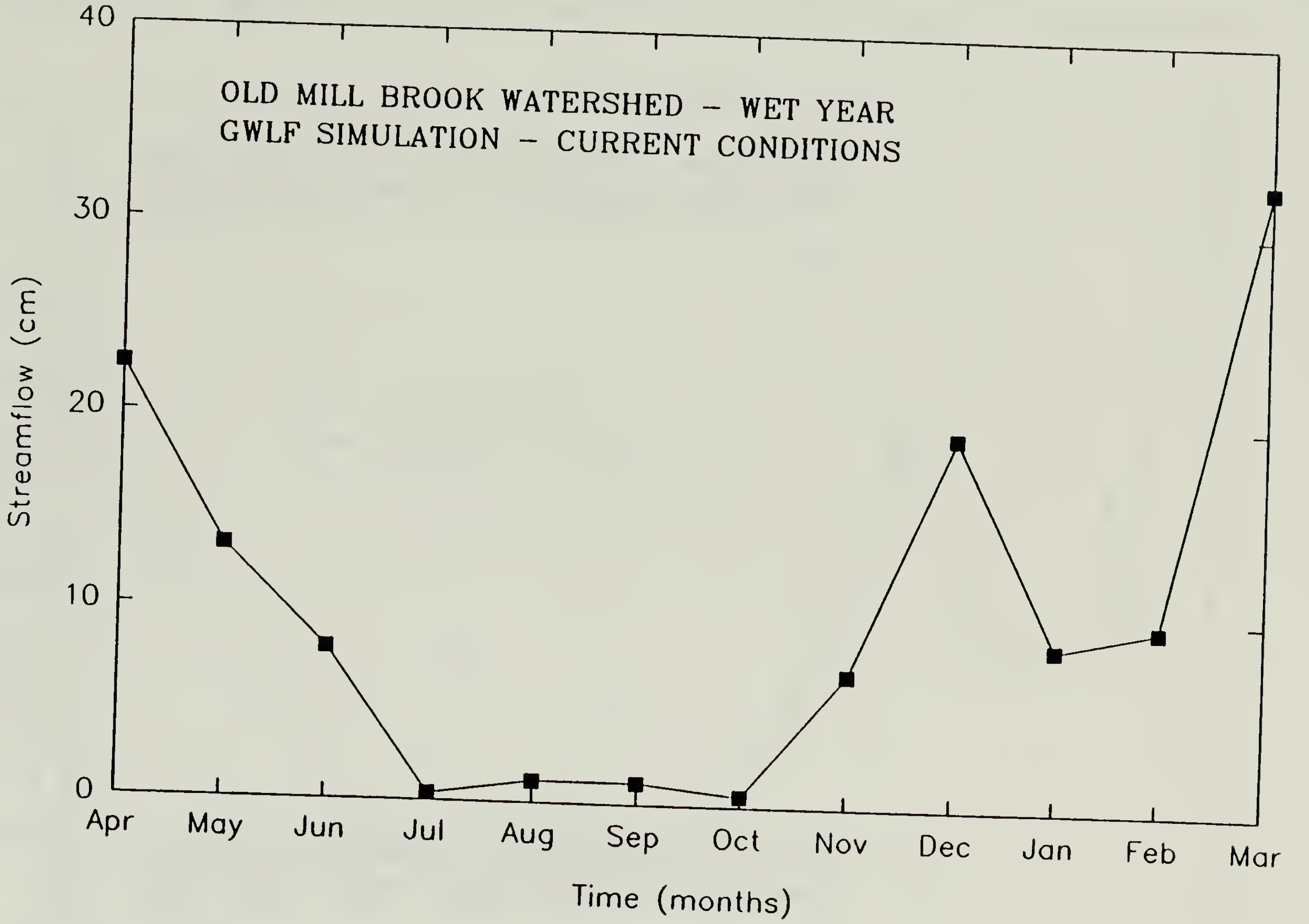

Figure I-1. Streamflow Simulation from the GWLF Model for the Old Mill Brook Watershed During the Wet Year.

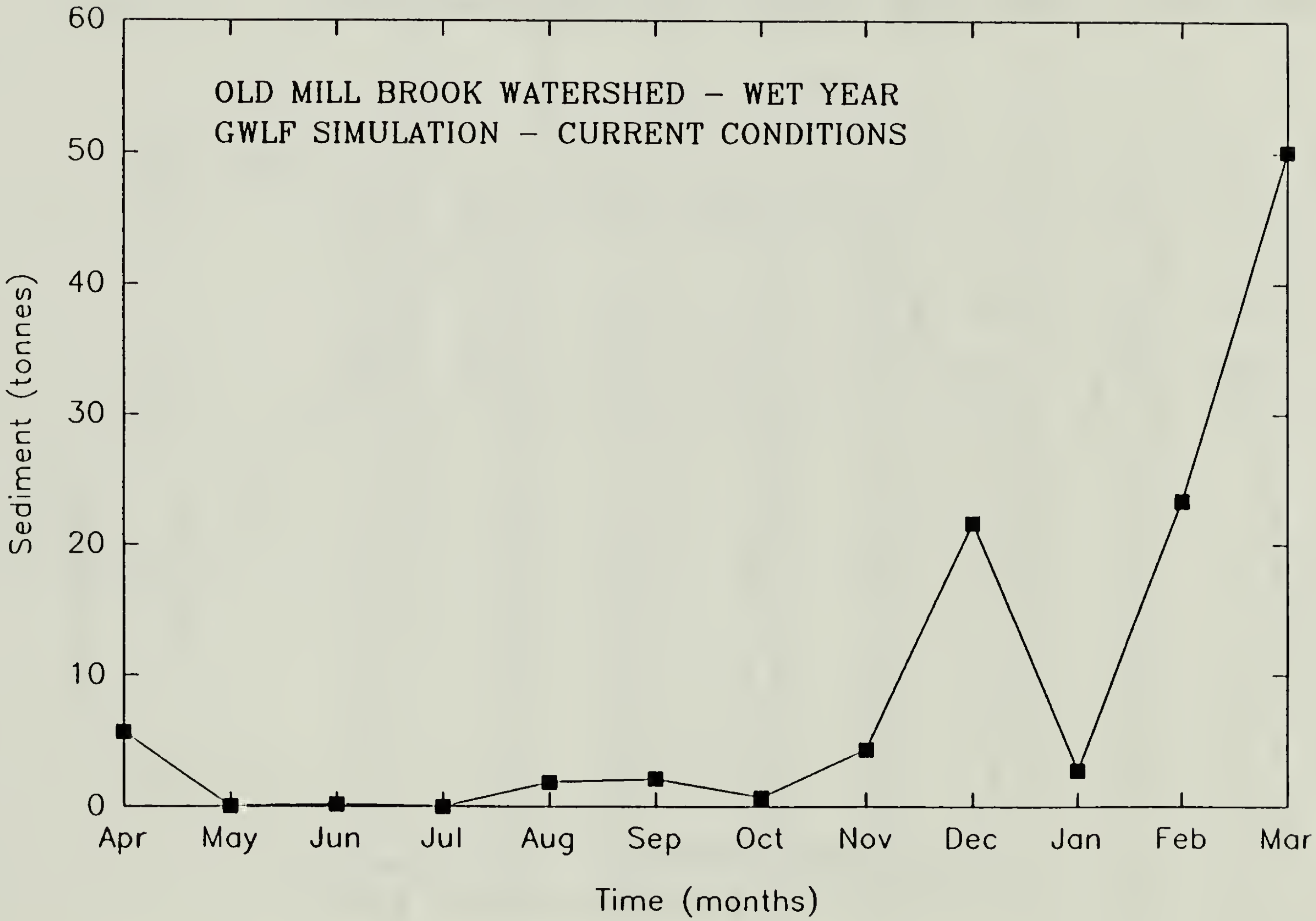

Figure I-2. **Sediment Simulation from the GWLF Model for the Old Mill Brook Watershed During the Wet Year.**

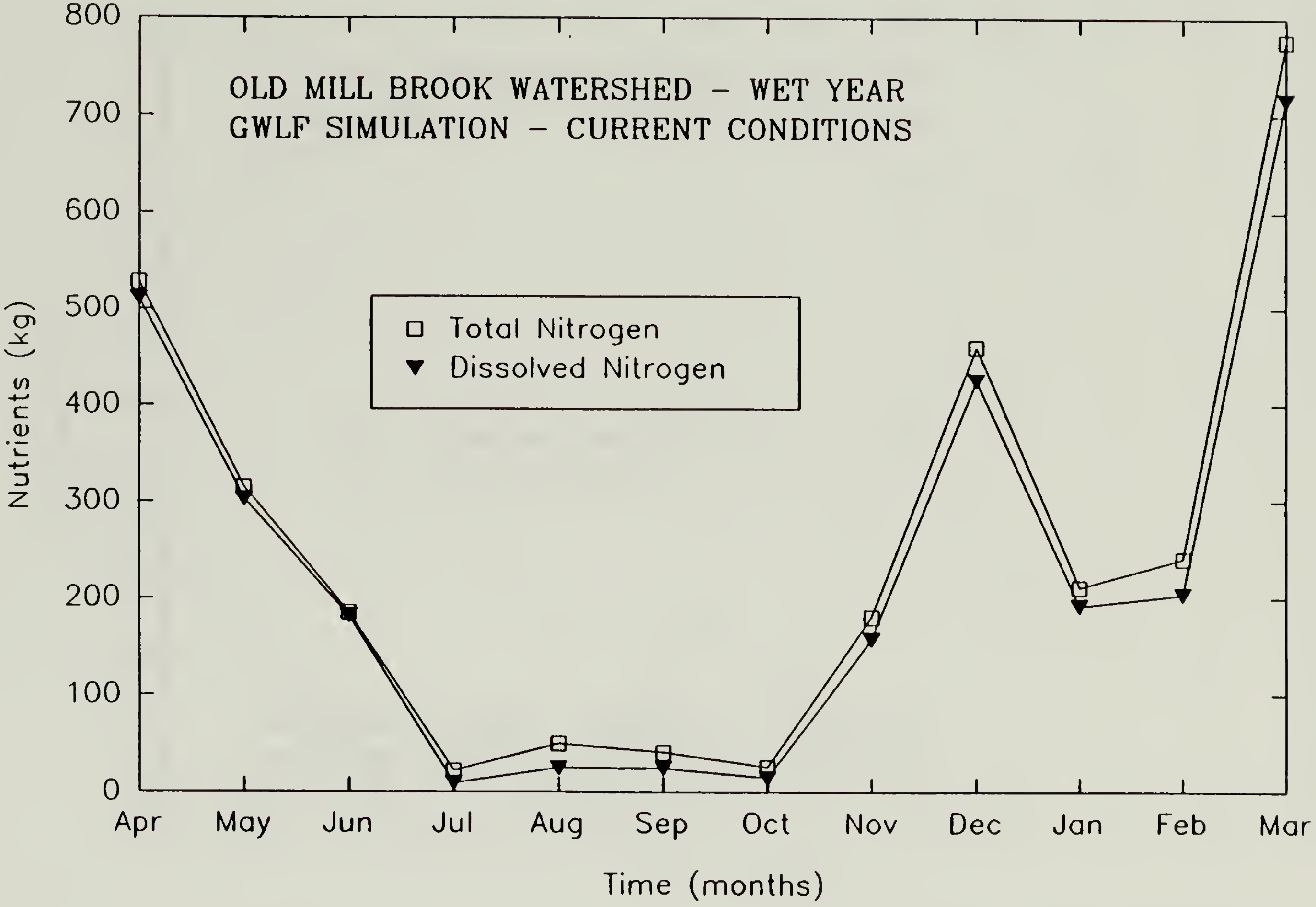

Figure I-3. Nitrogen Simulation from the GWLF Model for the Old Mill Brook Watershed During the Wet Year.

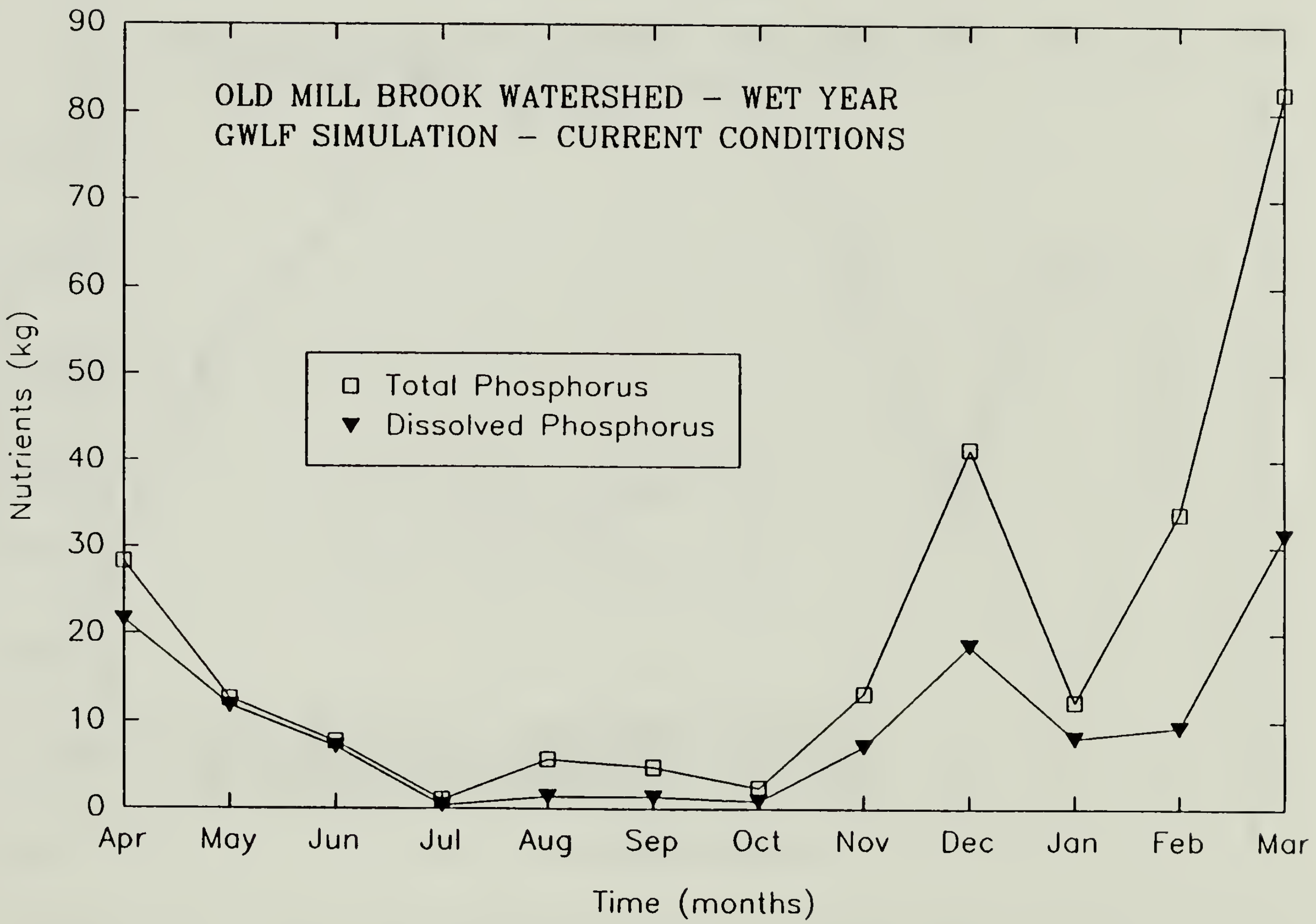

Figure I-4. **Phosphorus Simulation from the GWLF Model for the Old Mill Brook Watershed During the Wet Year.**

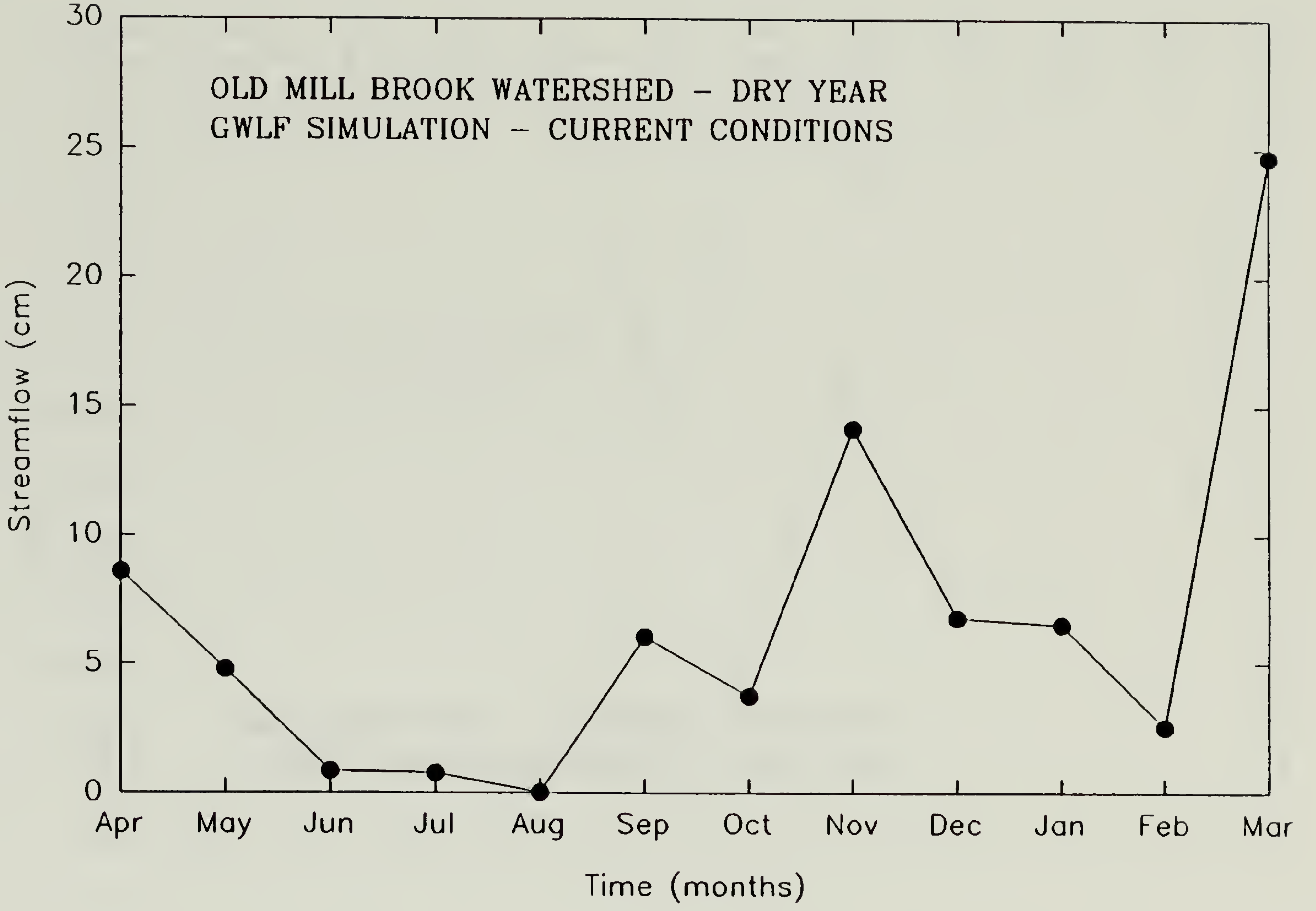

Figure I-5. Streamflow Simulation from the GWLF Model for the Old Mill Brook Watershed During the Dry Year.

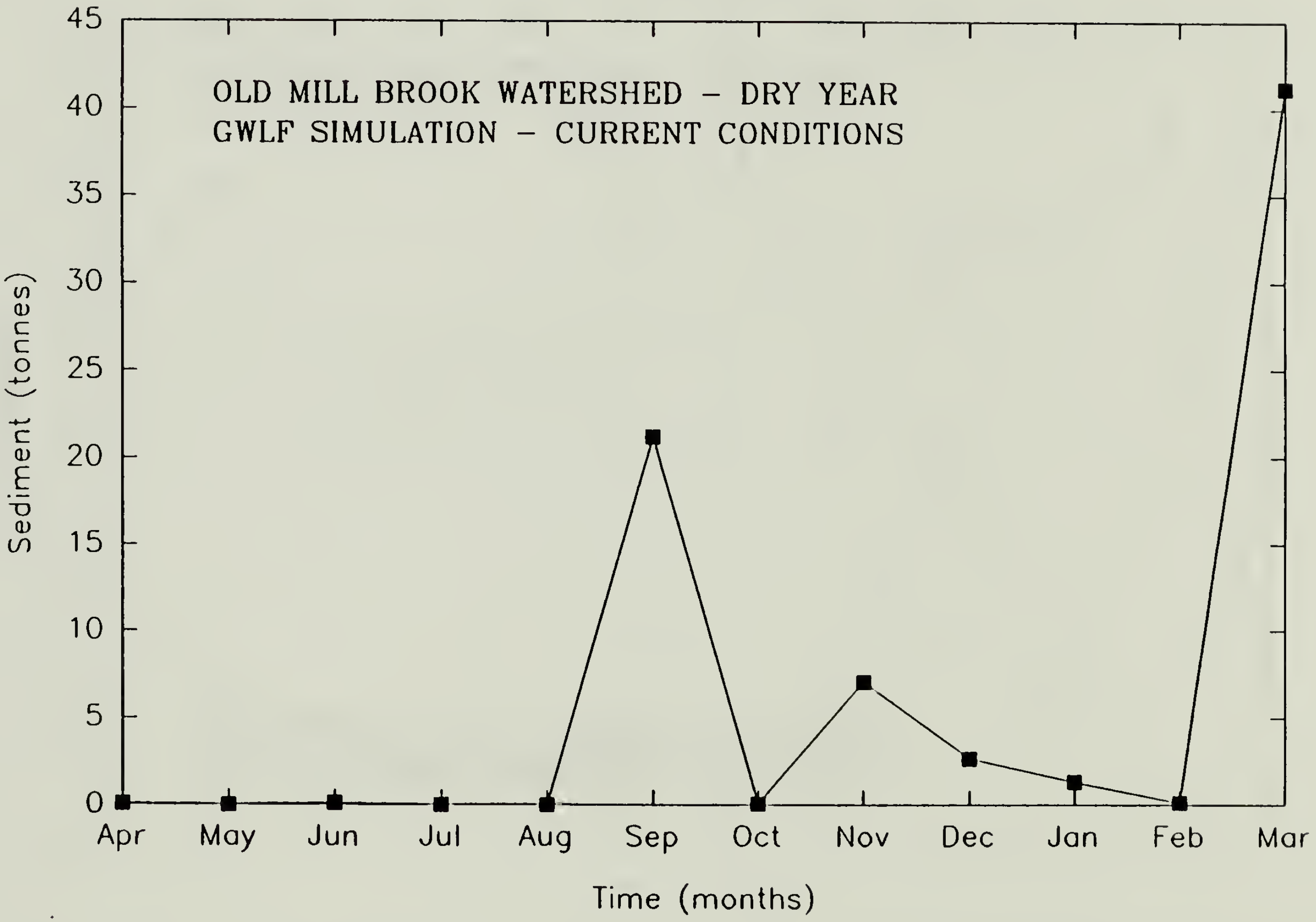

Figure I-6. Sediment Simulation from the GWLF Model for the Old Mill Brook Watershed During the Dry Year.

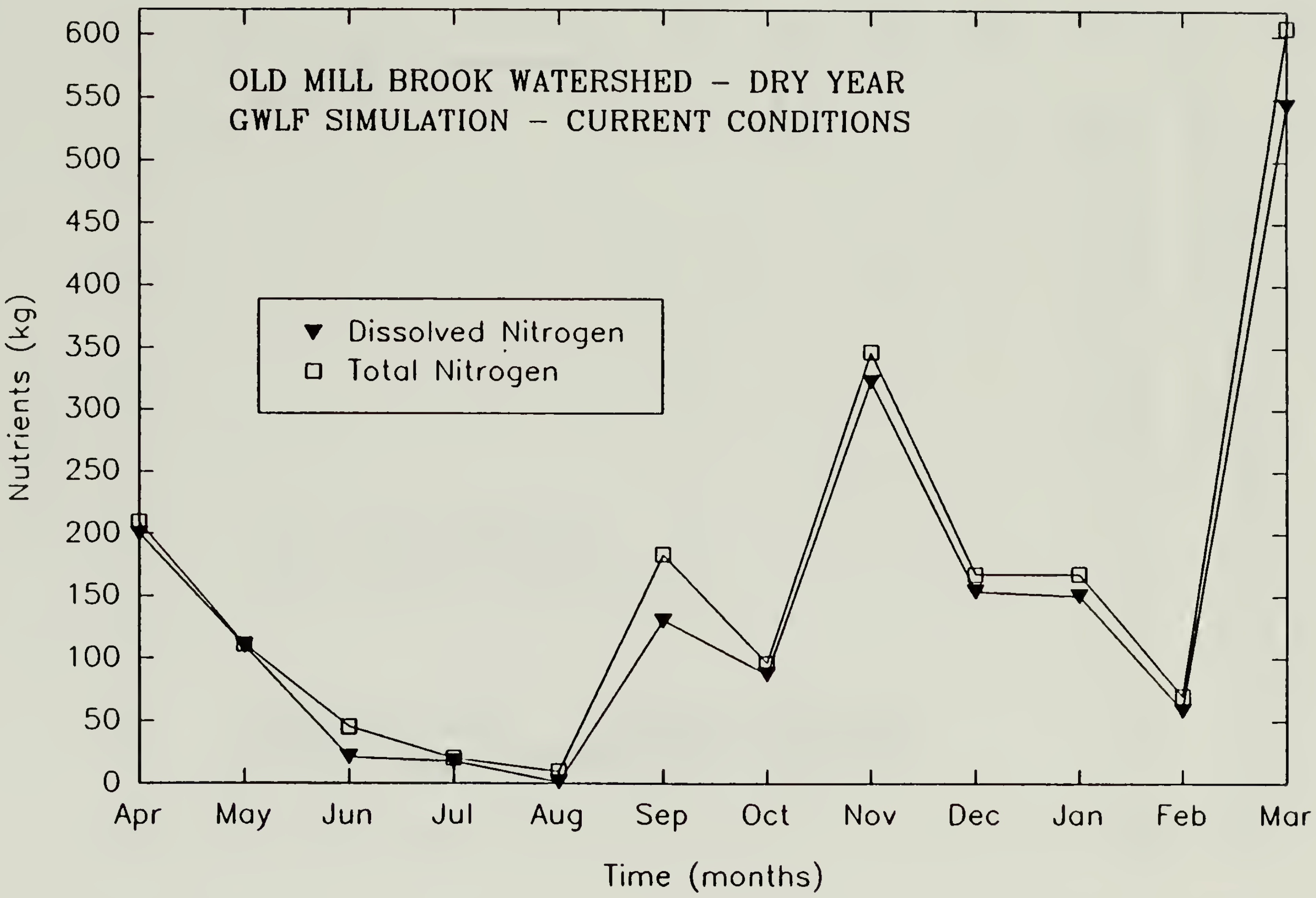

Figure I-7. Nitrogen Simulation from the GWLF Model for the Old Mill Brook Watershed During the Dry Year.

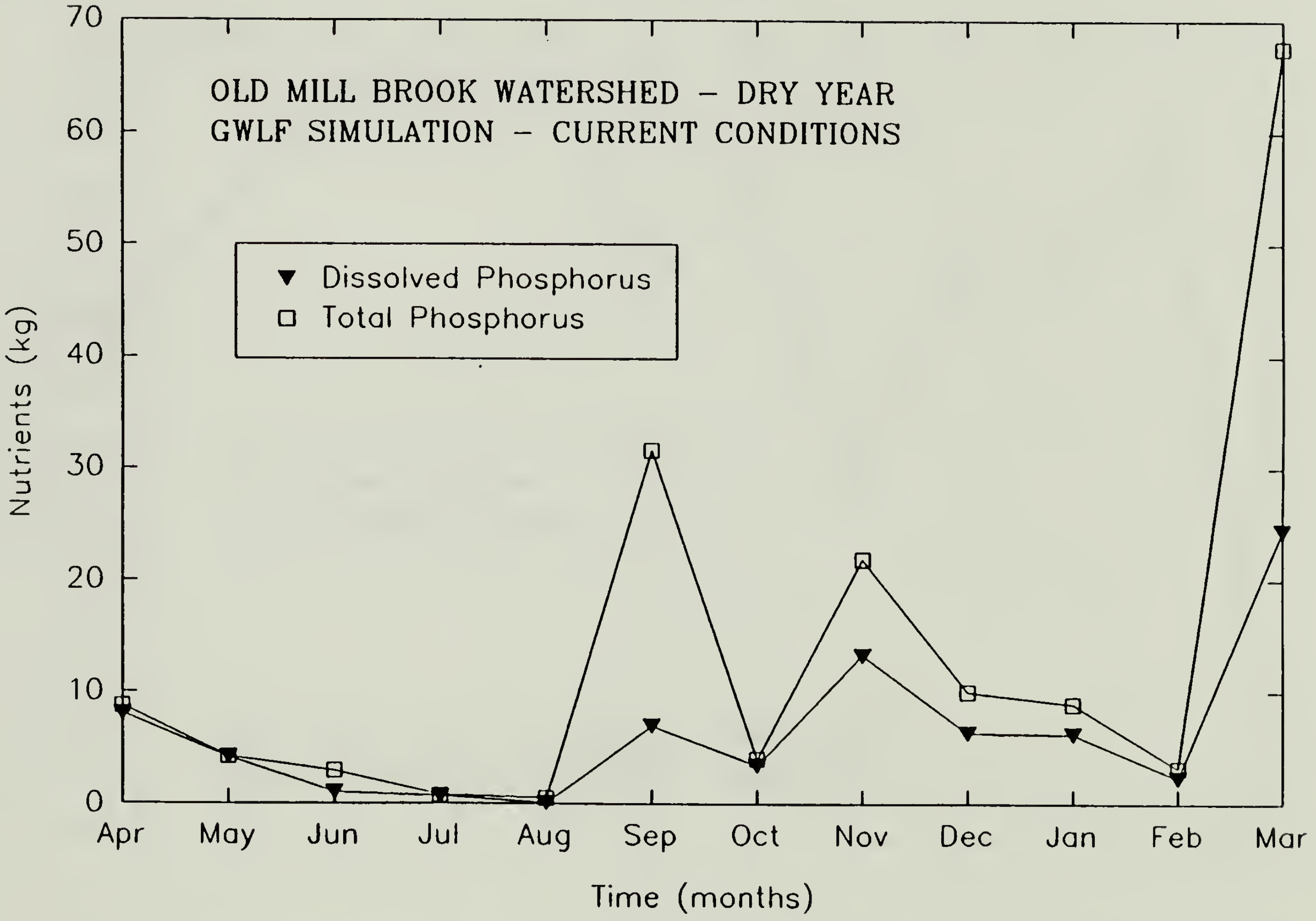

Figure I-8. Phosphorus Simulation from the GWLF Model for the Old Mill Brook Watershed During the Dry Year.

APPENDIX J

Figure J-1. Nitrogen Simulation from the GWLF model for the Altered Hadlock Brook Watershed During the Wet Year.

Figure J-2. Phosphorus Simulation from the GWLF model for the Altered Hadlock Brook Watershed During the Wet Year.

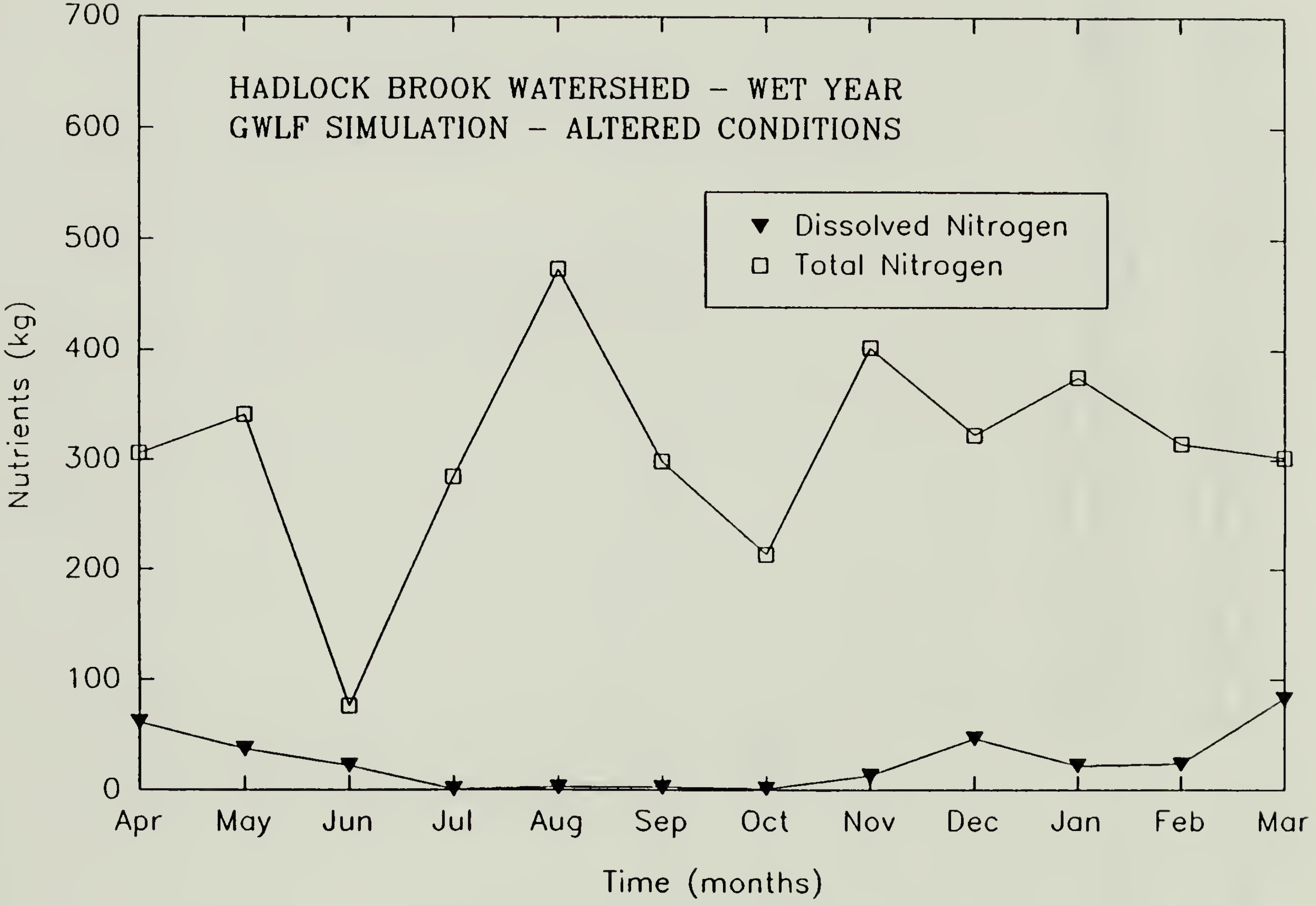

Figure J-1. Nitrogen Simulation from the GWLF Model for the Altered Hadlock Brook Watershed During the Wet Year.

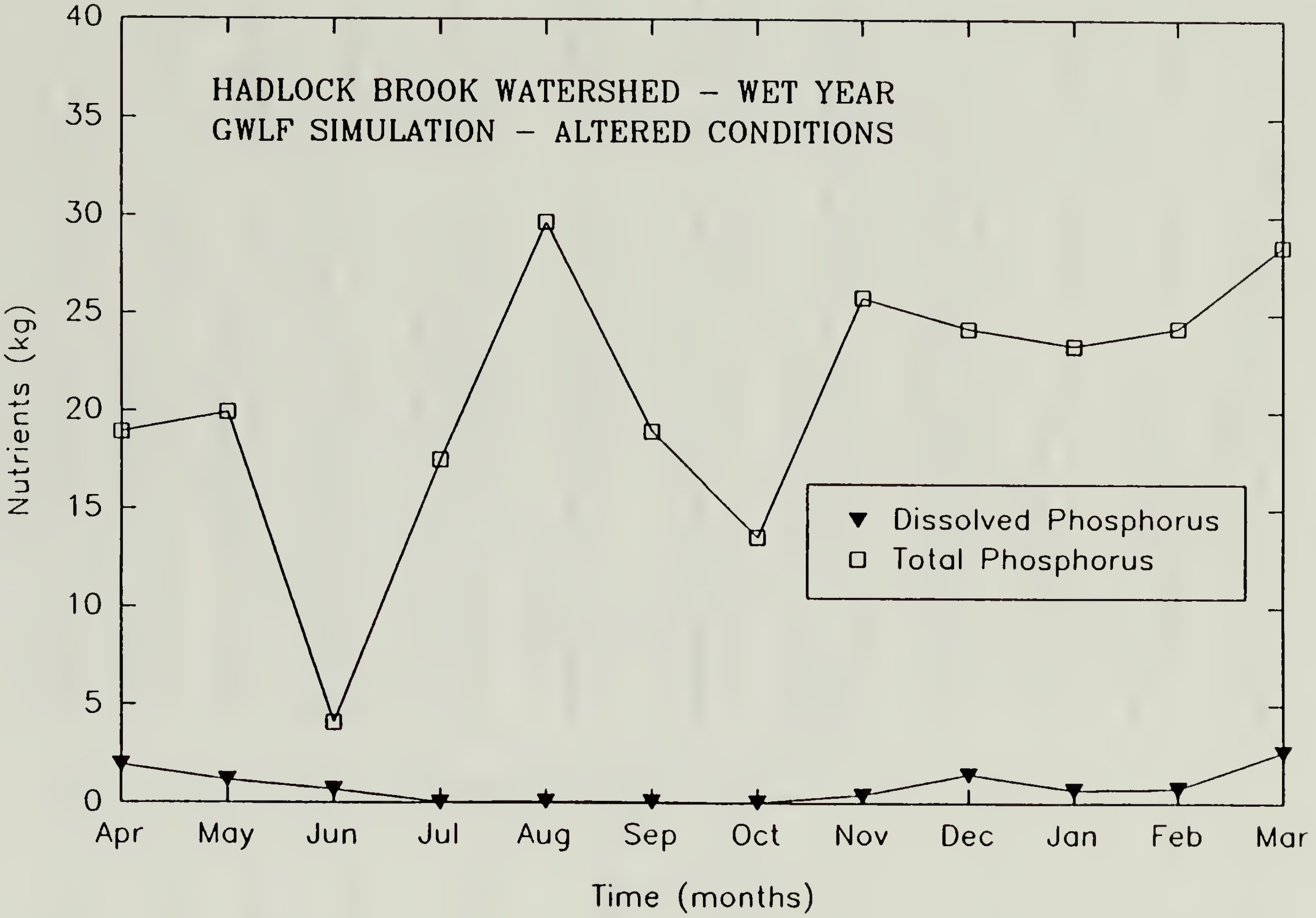

Figure J-2. Phosphorus Simulation from the GWLF Model for the Altered Hadlock Brook Watershed During the Wet Year.

APPENDIX K

Figure K-1. Sensitivity Analysis: Effect of Curve Number on Streamflow.

Figure K-2. Sensitivity Analysis: Effect of Curve Number on Sediment.

Figure K-3. Sensitivity Analysis: Effect of KLSCP Factor on Sediment.

Figure K-4. Sensitivity Analysis: Effect of Evapotranspiration Cover Coefficient for the Month of September on Streamflow.

Figure K-5. Sensitivity Analysis: Effect of Average Monthly Daylight Hours for the Month of September on Streamflow.

Figure K-6. Sensitivity Analysis: Effect of Growing Season Parameter for the Month of September on Streamflow.

Figure K-7. Sensitivity Analysis: Effect of Growing Season Parameter for the Month of September on Sediment.

Figure K-8. Sensitivity Analysis: Effect of the Erosion Coefficient Parameter for the Month of September on Sediment.

Figure K-9. Sensitivity Analysis: Effect of Initial Saturated Storage on Streamflow.

Figure K-10. Sensitivity Analysis: Effect of Recession Constant on Streamflow.

Figure K-11. Sensitivity Analysis: Effect of Seepage Constant on Streamflow.

Figure K-12. Sensitivity Analysis: Effect of the Sediment Delivery Ratio on Sediment.

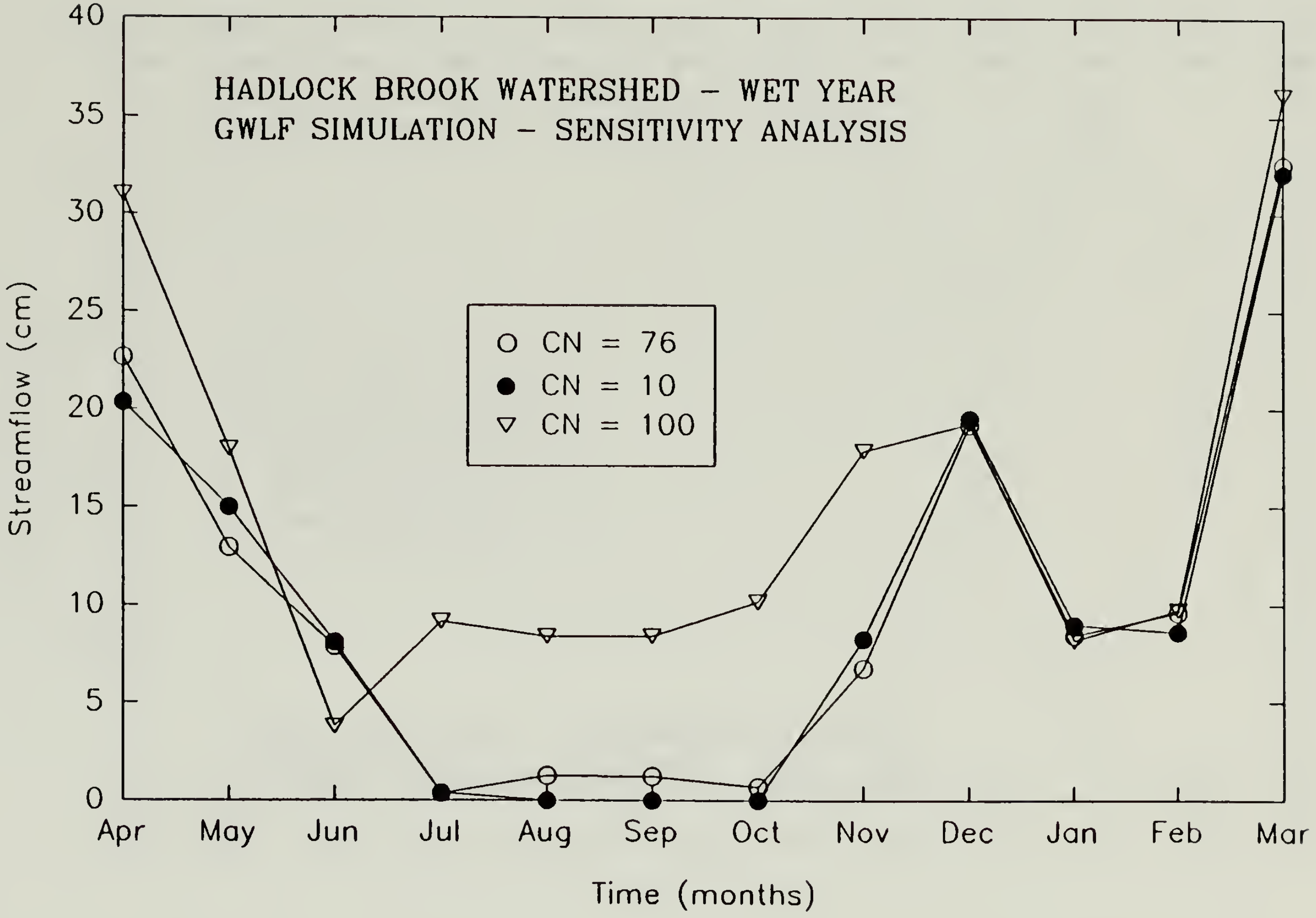

Figure K-1. **Sensitivity Analysis: Effect of Curve Number on Stream Flow for the Hadlock Brook Watershed During the Wet Year.**

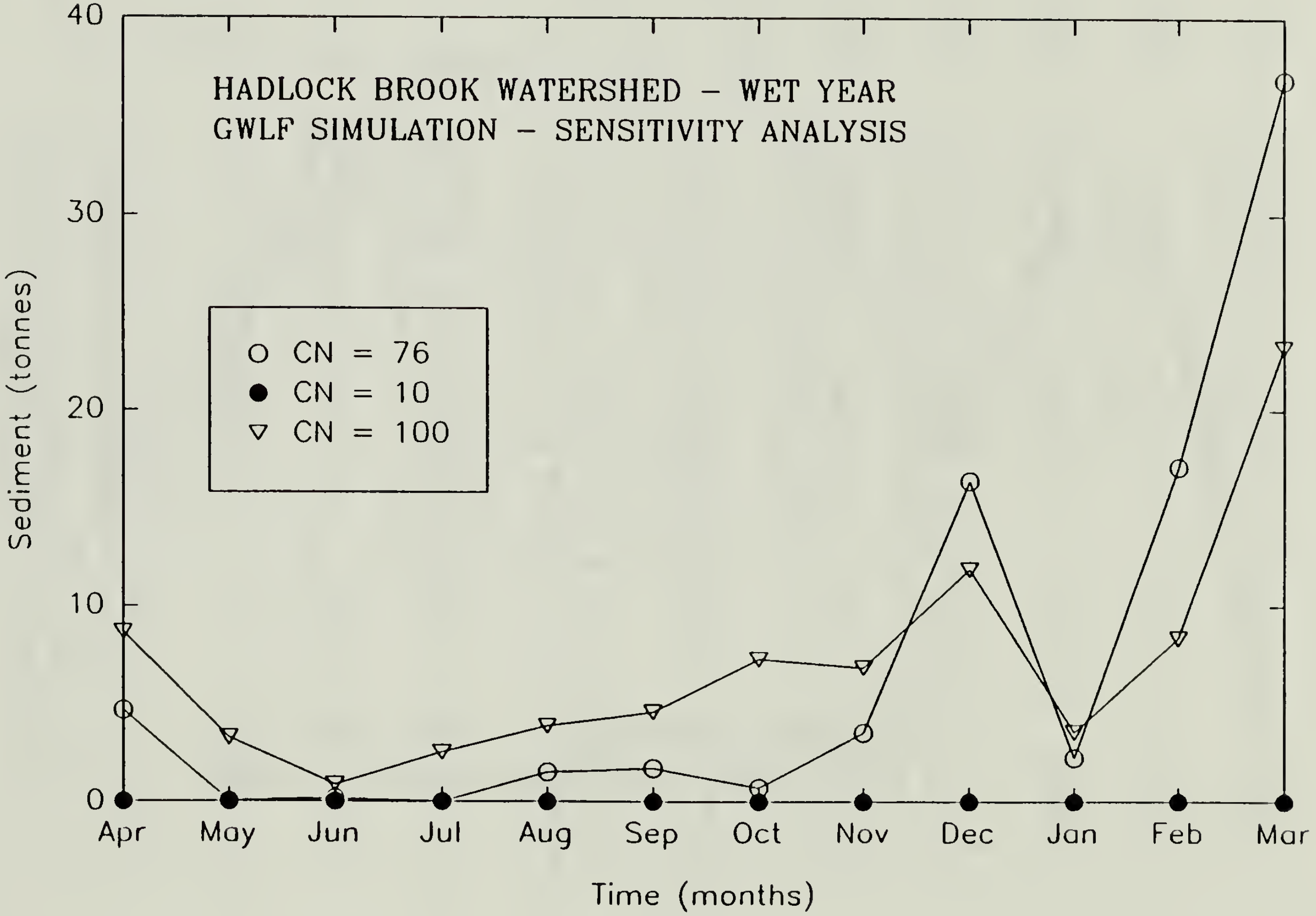

Figure K-2. Sensitivity Analysis: Effect of Curve Number on Sediment Mass for the Hadlock Brook Watershed During the Wet Year.

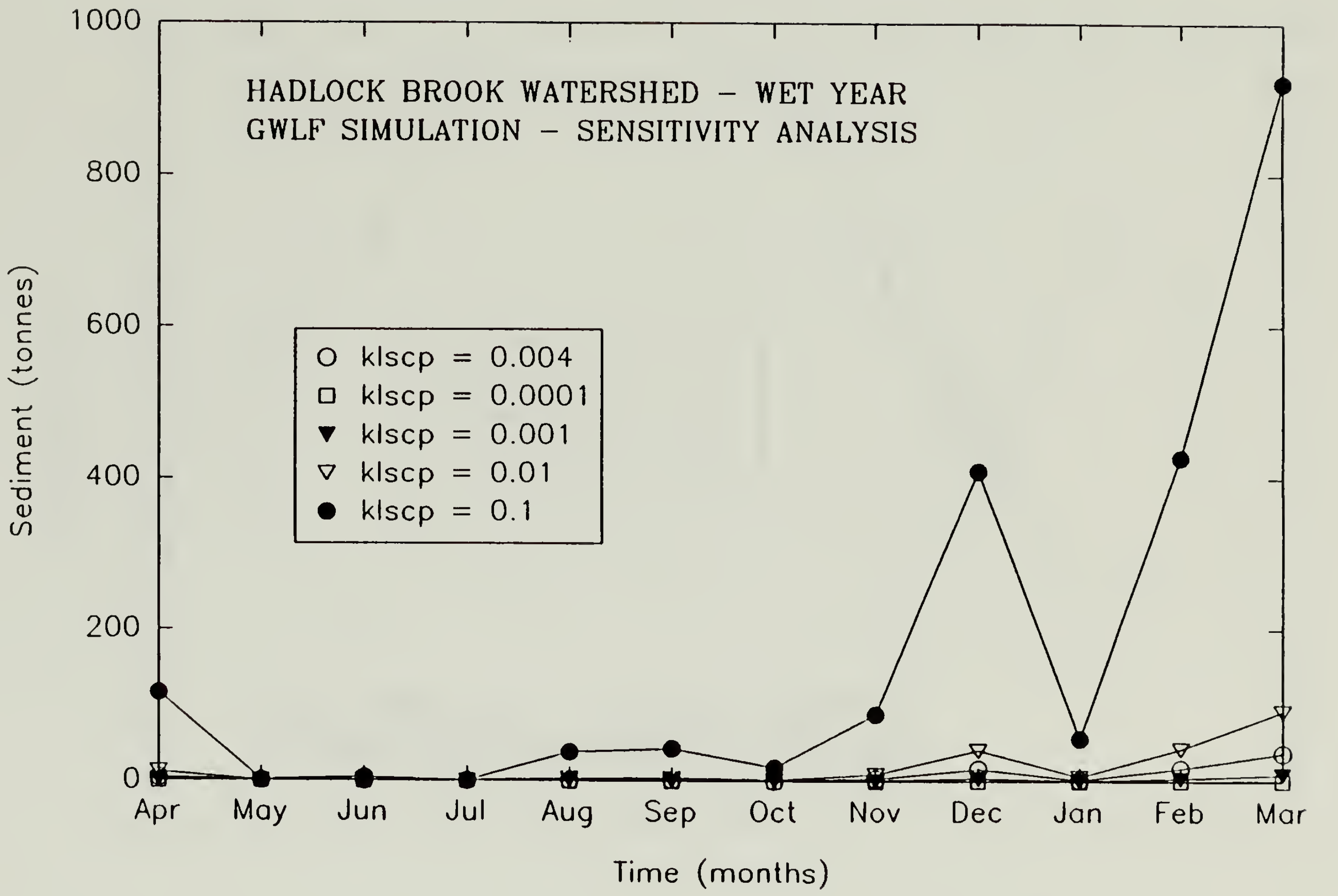

Figure K-3. Sensitivity Analysis: Effect of KLSCP Factor on Sediment Mass for the Hadlock Brook Watershed During the Wet Year.

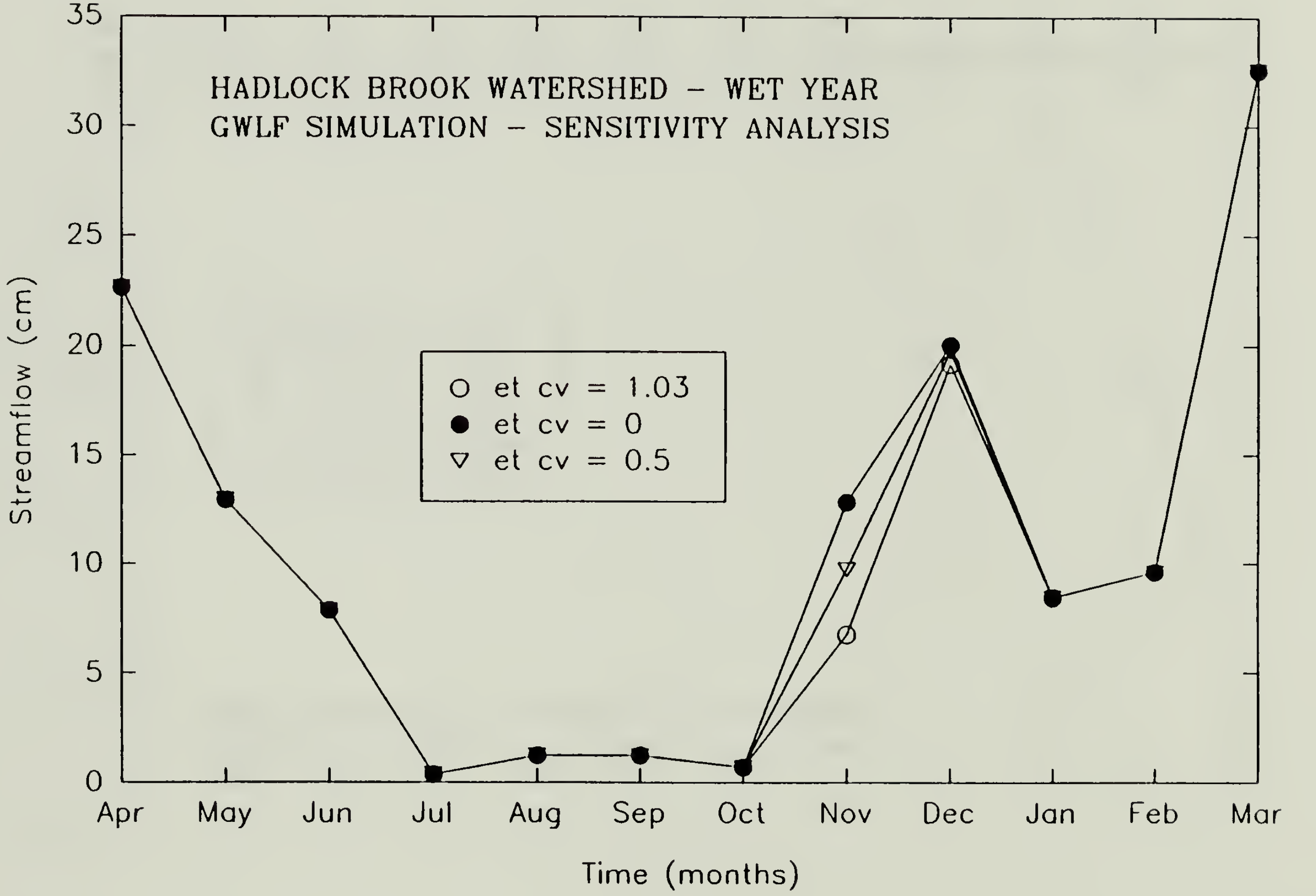

Figure K-4. Sensitivity Analysis: Effect of Evapotranspiration Cover Coefficient for the Month of September on Streamflow for the Hadlock Brook Watershed During the Wet Year.

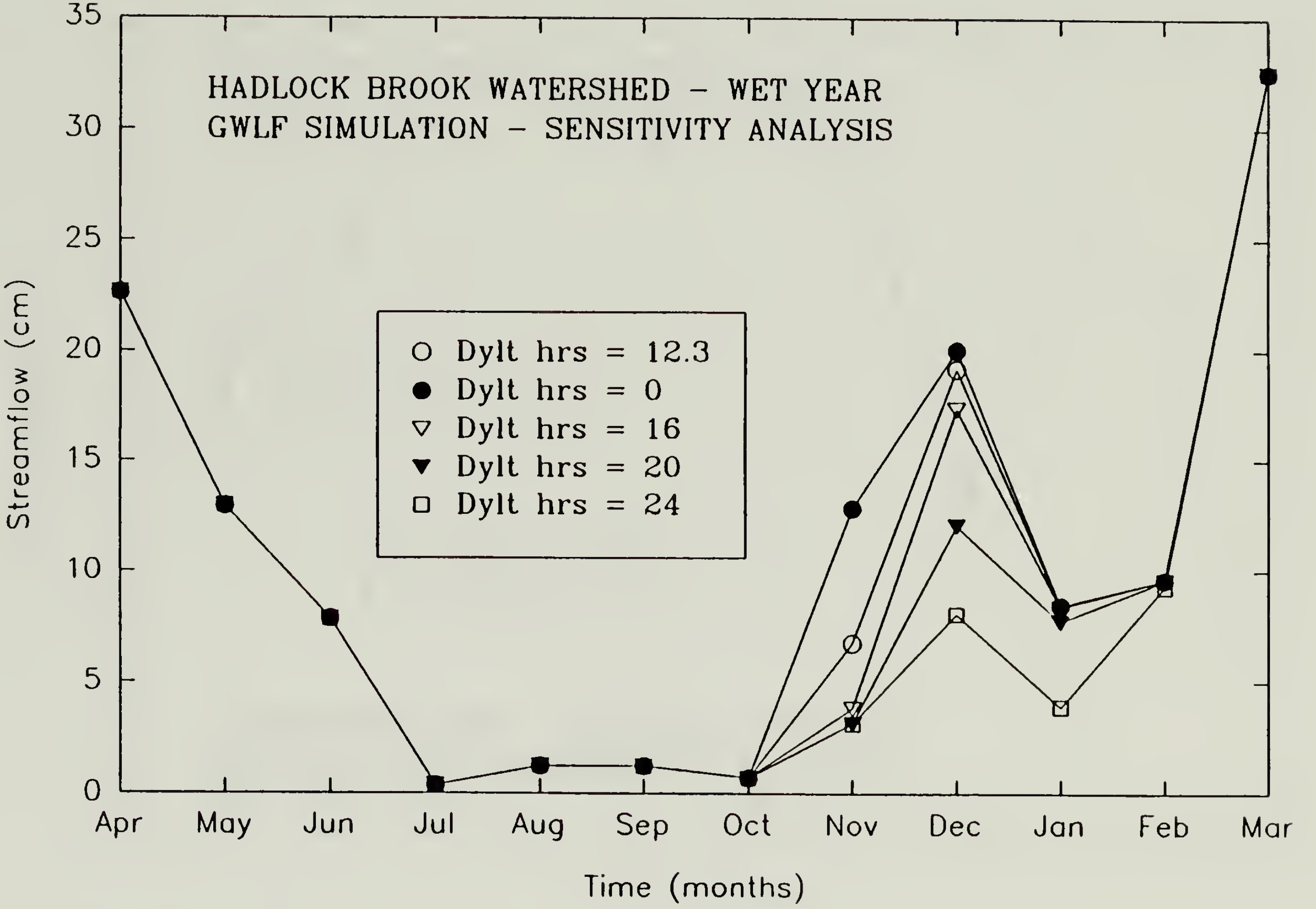

Figure K-5. Sensitivity Analysis: Effect of Average Monthly Daylight Hours for the Month of September on Streamflow for the Hadlock Brook Watershed During the Wet Year.

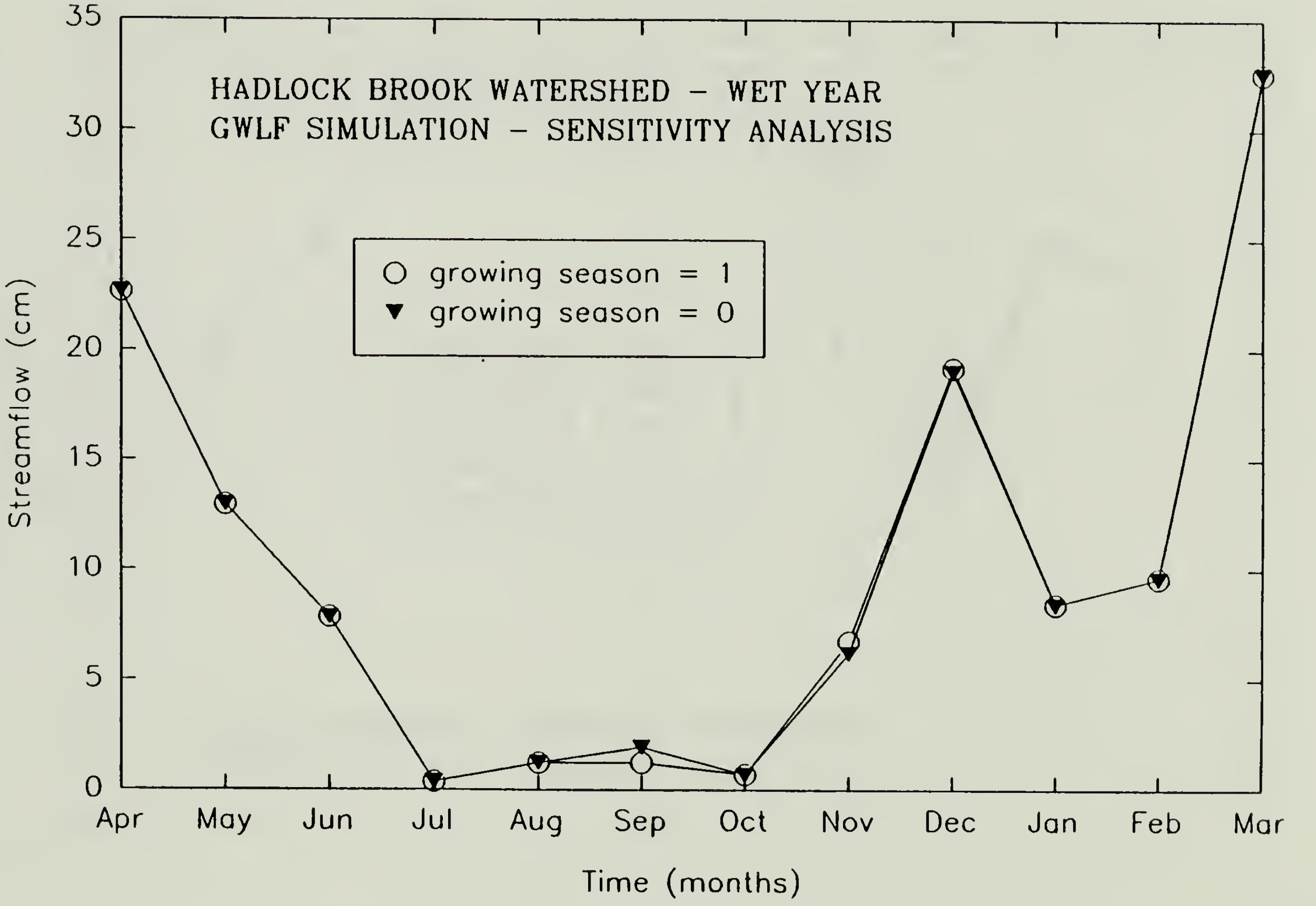

Figure K-6. Sensitivity Analysis: Effect of Growing Season Parameter for the Month of September on Streamflow for the Hadlock Brook Watershed During the Wet Year.

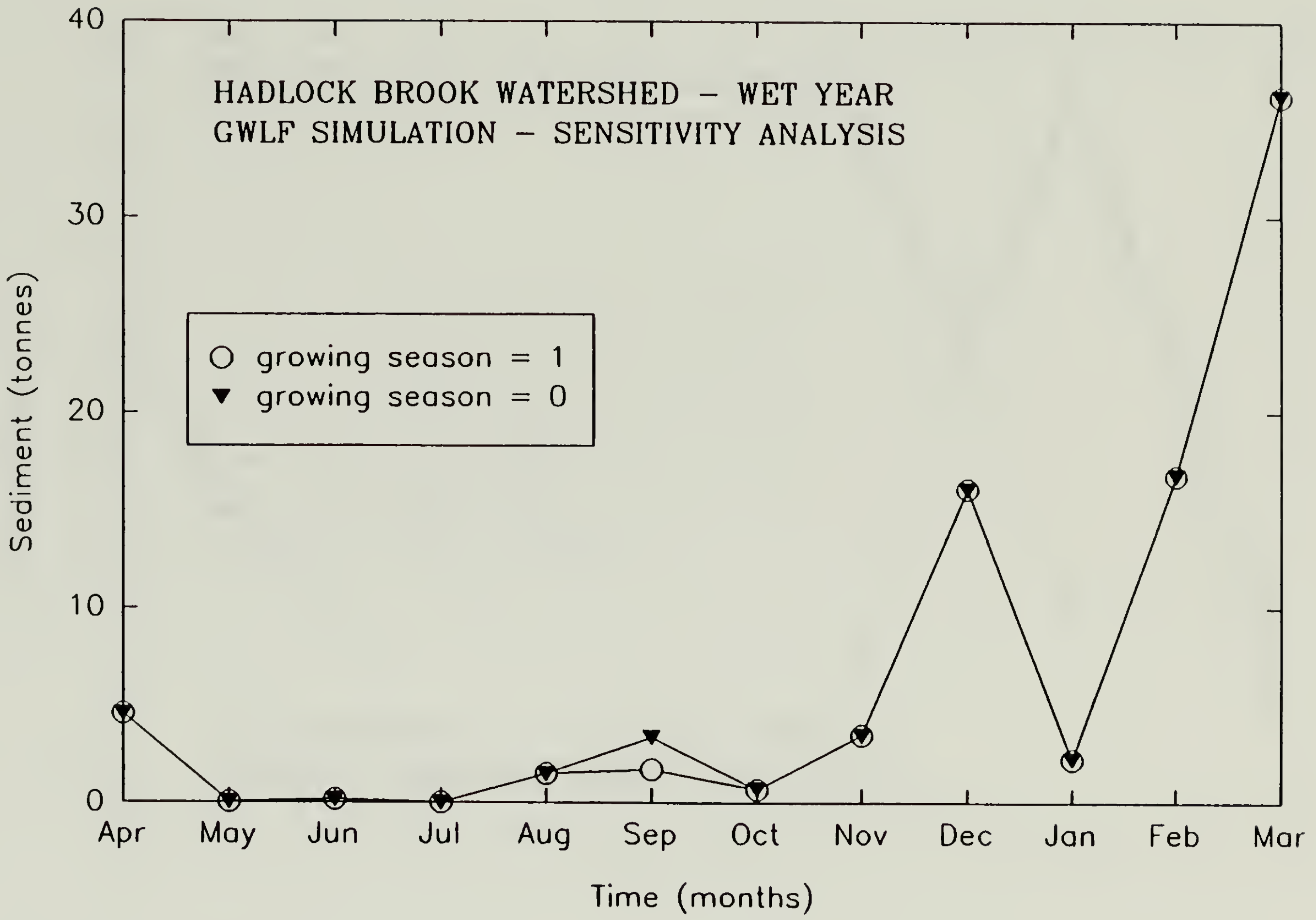

Figure K-7. Sensitivity Analysis: Effect of Growing Season Parameter for the Month of September on Sediment Mass for the Hadlock Brook Watershed During the Wet Year.

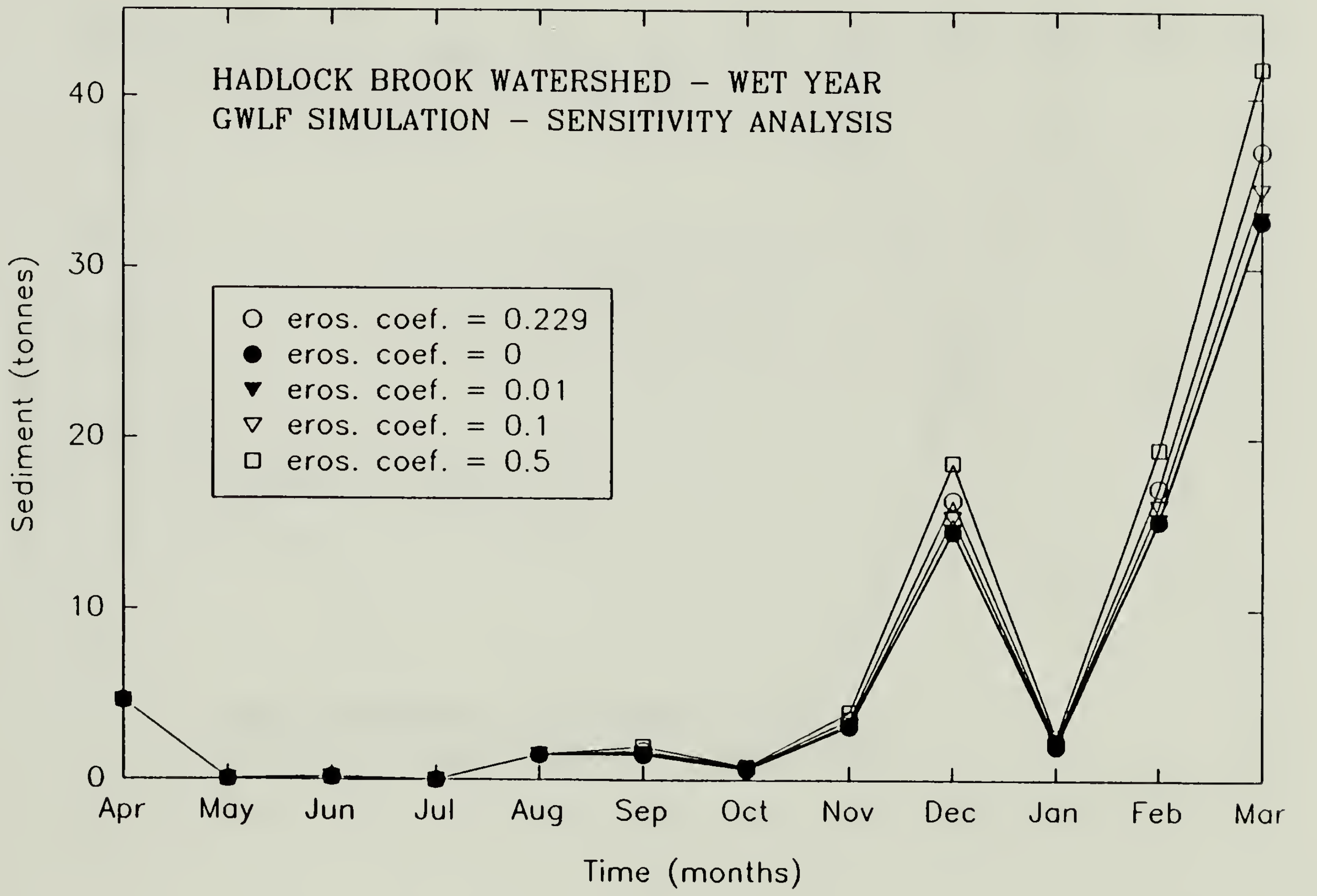

Figure K-8. Sensitivity Analysis: Effect of the Erosion Coefficient Parameter for the Month of September on Sediment Mass for the Hadlock Brook Watershed During the Wet Year.

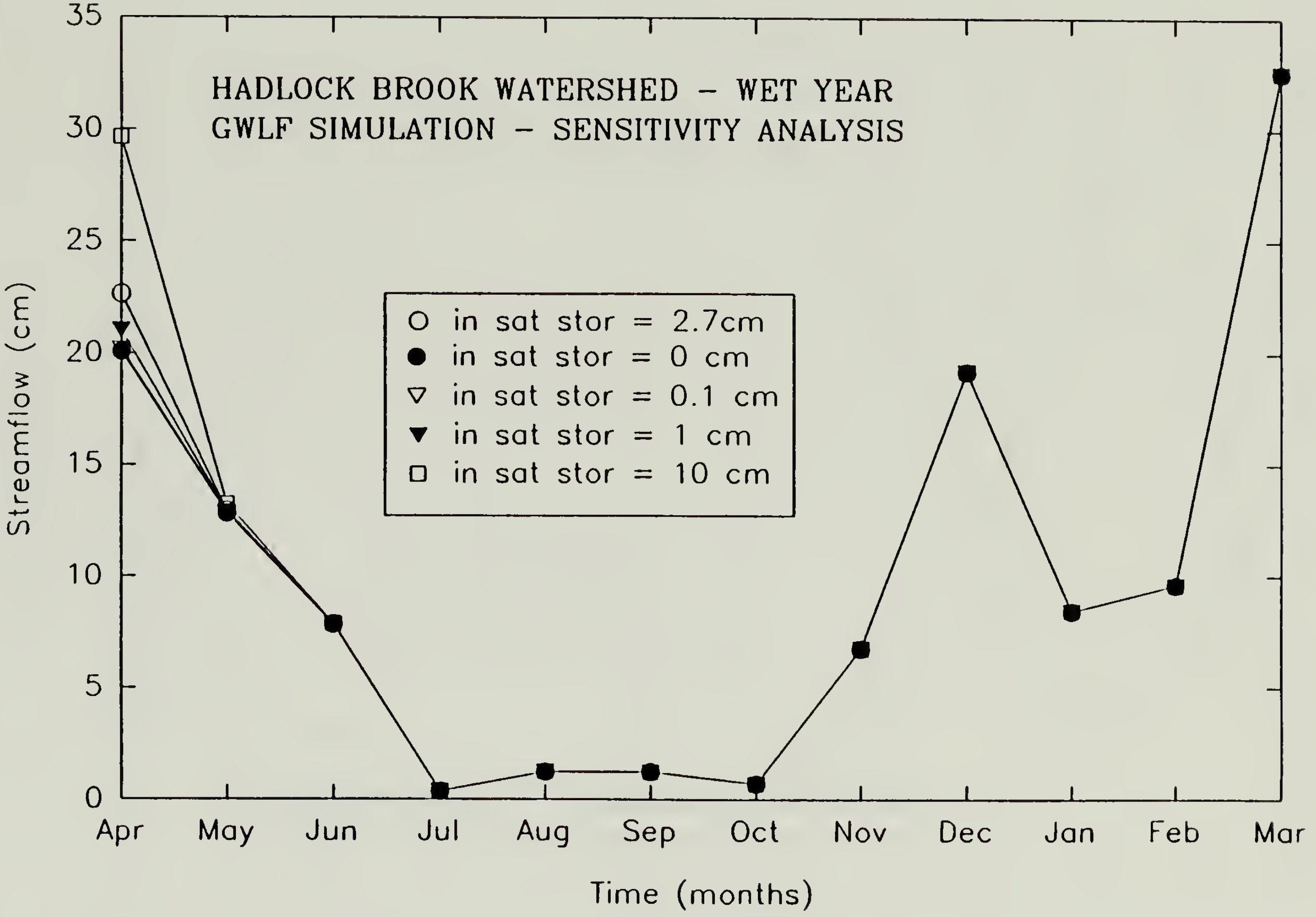

Figure K-9. **Sensitivity Analysis: Effect of Initial Saturated Storage Parameter for the Month of September on Sediment Mass for the Hadlock Brook Watershed During the Wet Year.**

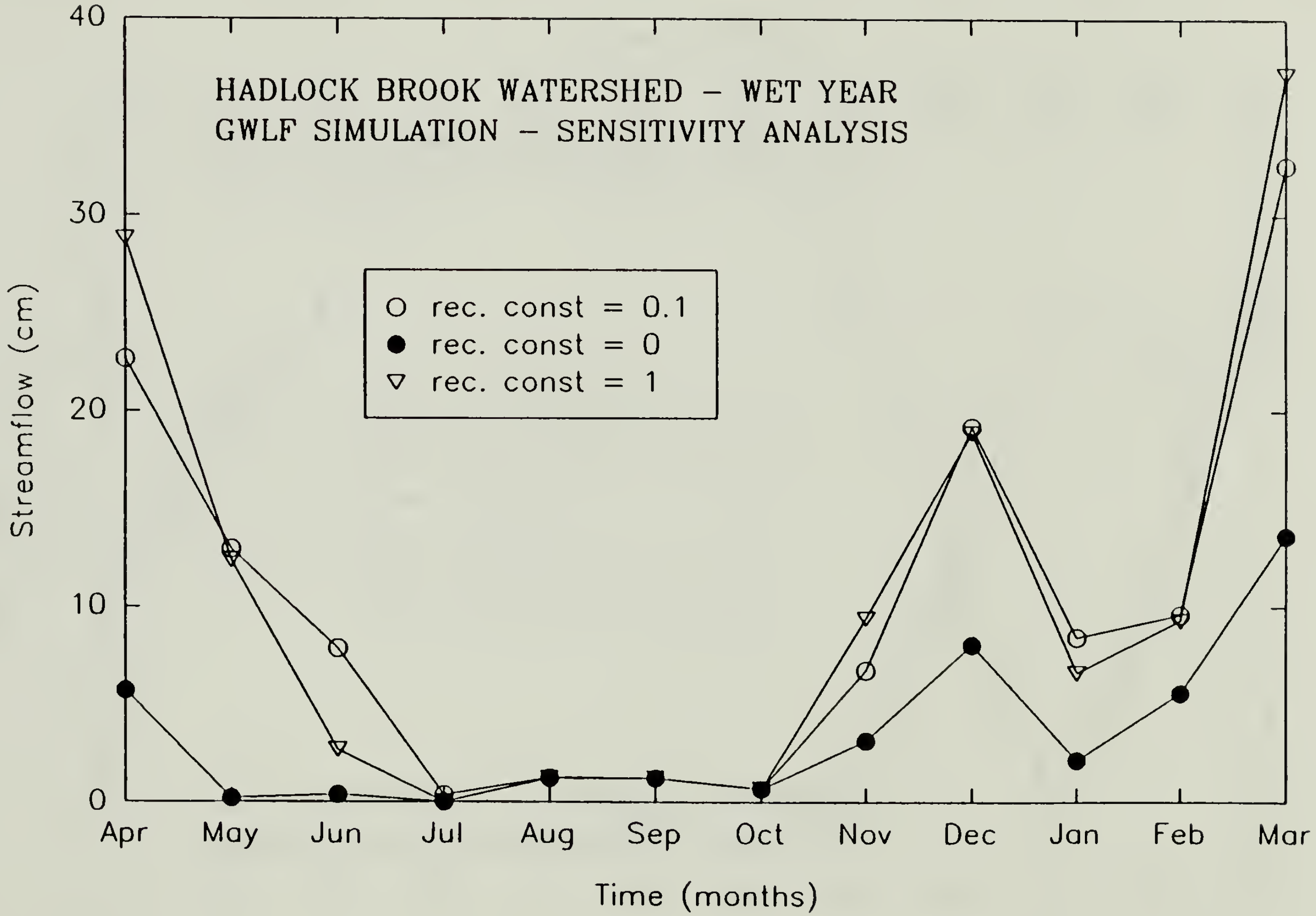

Figure K-10. **Sensitivity Analysis: Effect of Recession Constant on Streamflow for the Hadlock Brook Watershed During the Wet Year.**

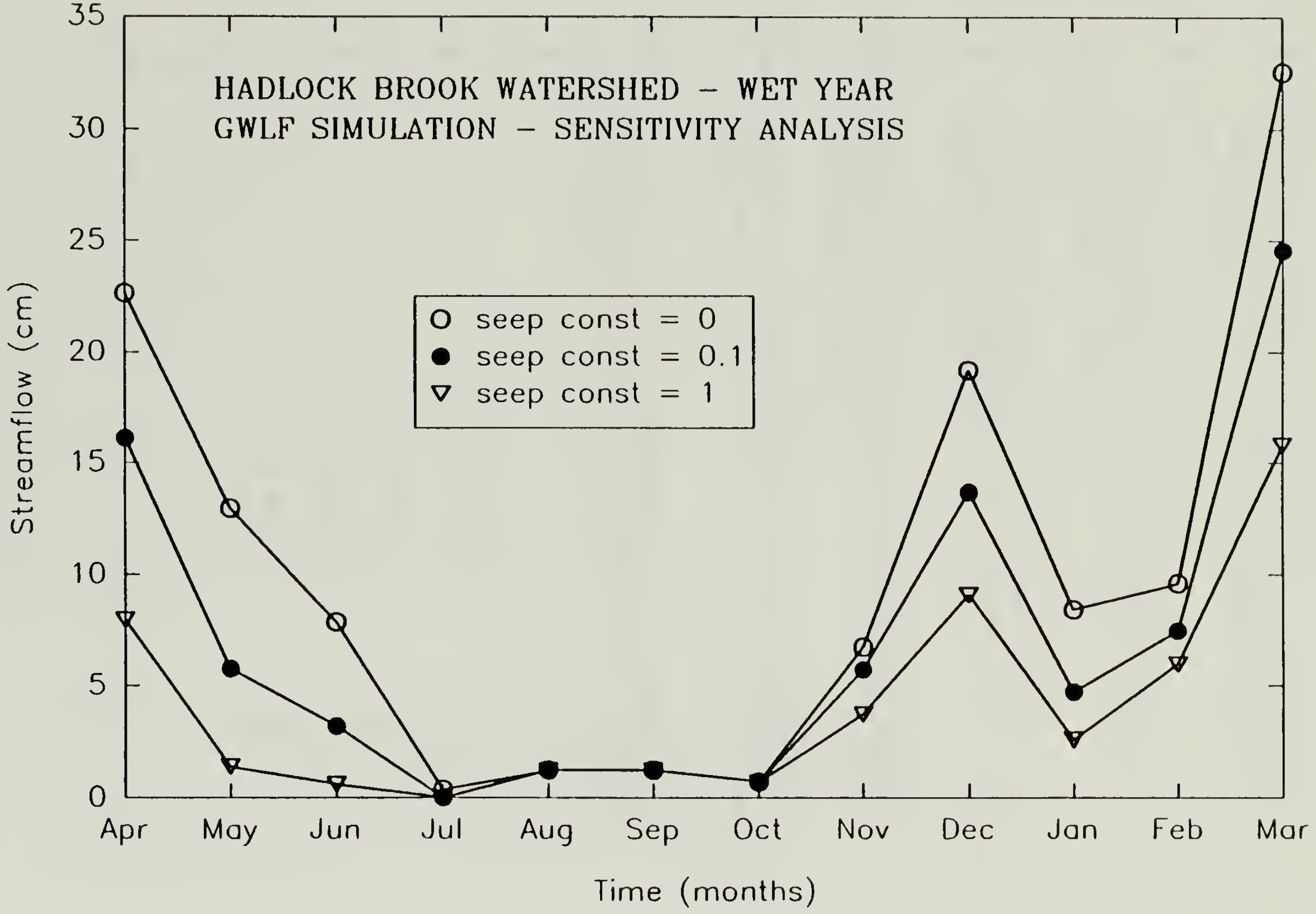

Figure K-11. Sensitivity Analysis: Effect of Seepage Constant on Streamflow for the Hadlock Brook Watershed During the Wet Year.

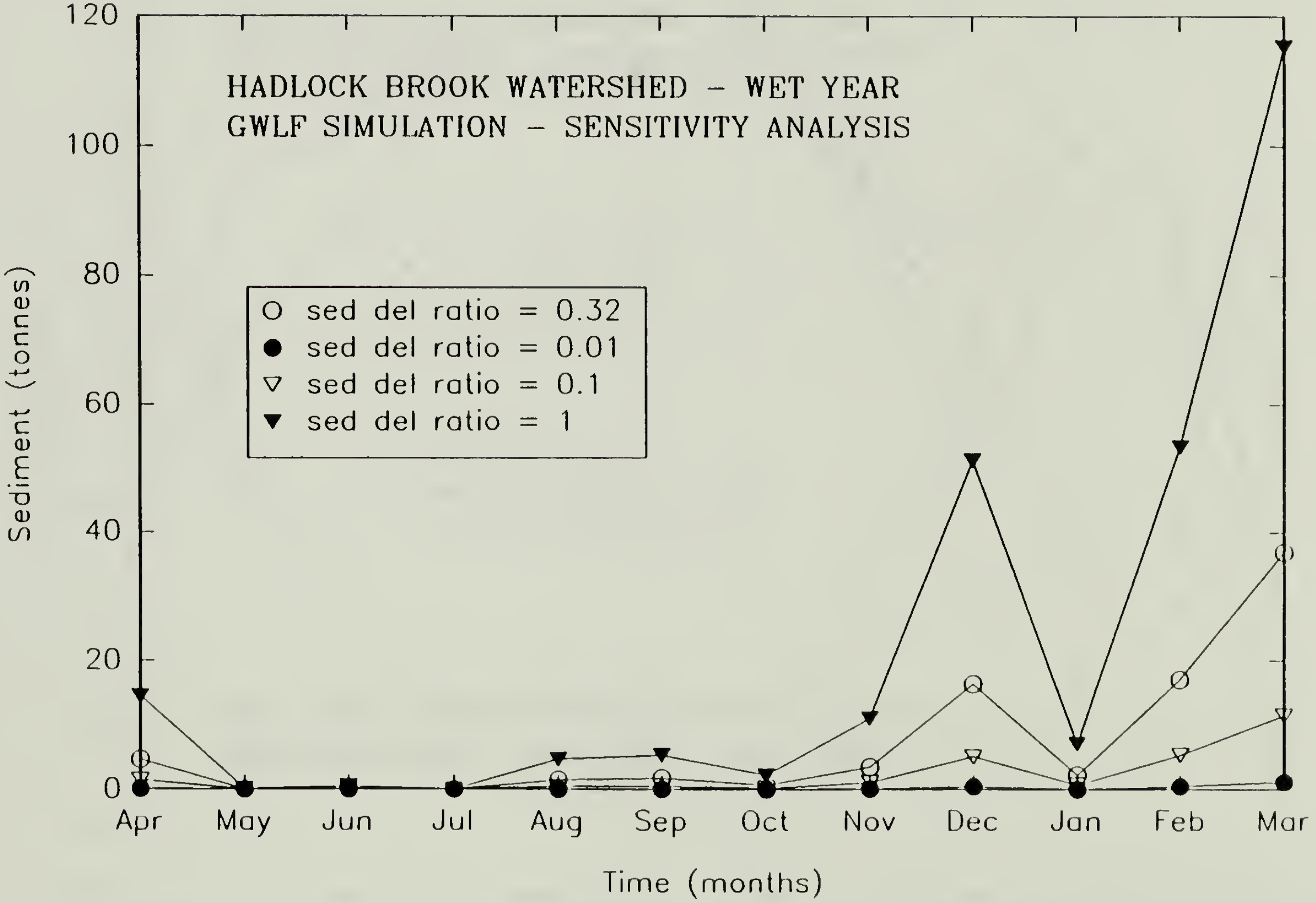

Figure K-12. Sensitivity Analysis: Effect of the Sediment Delivery Ratio on Sediment for the Hadlock Brook Watershed During the Wet Year.

APPENDIX L

Table L-1. Summary of Water Quality and Quantity Parameters Collected at Upper Hadlock Brook Watershed; Site 1.

Table L-2. Summary of Water Quality and Quantity Parameters Collected at Upper Hadlock Brook Watershed; Site 2.

Table L-3. Summary of Water Quality and Quantity Parameters Collected at Upper Hadlock Brook Watershed; Site 3.

Table L-4. Summary of Water Quality and Quantity Parameters Collected at Old Mill Brook Watershed; Site 1.

Table L-5. Summary of Water Quality and Quantity Parameters Collected at Marshall Watershed; Site 1.

Table L-6. Summary of Water Quality and Quantity Parameters Collected at Marshall Brook Watershed; Site 2.

Table L-1

Summary of Water Quality and Quantity Data Collected at Upper Hadlock Watershed, Site 1 Acadia National Park

UPPER HADLOCK WATERSHED
Site 1: Upper Hadlock Brook

Run	Date	Time	Temp (°C)	Sodium (mg/L)	Chloride (mg/L)	Sodium/ Chloride	Cond (μmho/cm)	DO (mg/L)	Stage (ft)	Flow (cfs)
A	100590	1445	12.1	3.0	5.4	0.56	35.0	9.6	NDR	0.41
B	100690	1500	14.1	NDR	NDR	NDR	35.0	9.5	3.04	0.22
C	111590	1300	5.1	4.0	6.7	0.60	25.0	11.4	2.95	1.09
D	111690	0930	5.6	4.3	15.2	0.28	28.0	12.0	2.95	1.79
E	041591	1200	4.5	NDR	NDR	NDR	20.0	NDR	2.93	NDR

Temp = temperature
DO = dissolved oxygen
μmho/cm = micromho per centimeter
NDR = not determined

Cond = conductivity
°C = celsius
mg/L = milligrams per liter

Table L-2

Summary of Water Quality and Quantity Data Collected at Upper Hadlock Watershed, Site 2
Acadia National Park

UPPER HADLOCK WATERSHED
Site 2: Upper Hadlock Brook (Right Fork)

Run	Date	Time	Temp (°C)	Sodium (mg/L)	Chloride (mg/L)	Sodium/ Chloride	Cond (µmho/cm)	DO (mg/L)	Stage (ft)	Flow (cfs)
A	111690	1030	NDR	NDR	NDR	NDR	NDR	NDR	NDR	0.37

Temp = temperature
DO = dissolved oxygen
µmho/cm = micromho per centimeter
NDR = not determined

Cond = conductivity
°C = celsius
mg/L = milligrams per liter

Table L-3

Summary of Water Quality and Quantity Data Collected at Upper Hadlock Watershed, Site 3 Acadia National Park

UPPER HADLOCK WATERSHED
Site 3: Upper Hadlock Brook (Left Fork)

Run	Date	Time	Temp (°C)	Sodium (mg/L)	Chloride (mg/L)	Sodium/ Chloride	Cond (µmho/cm)	DO (mg/L)	Stage (ft)	Flow (cfs)
A	111690	1030	6.0	NDR	NDR	NDR	26.0	12.0	NDR	0.30

Temp = temperature
DO = dissolved oxygen
µmho/cm = micromho per centimeter
NDR = not determined

Cond = conductivity
°C = celsius
mg/L = milligrams per liter

Table L-4

Summary of Water Quality and Quantity Data
Collected at Old Mill Watershed, Site 1
Acadia National Park

OLD MILL WATERSHED
Site 1: Old Mill Brook

Run	Date	Time	Temp (°C)	Sodium (mg/L)	Chloride (mg/L)	Sodium/ Chloride	Cond (µmho/cm)	DO (mg/L)	Stage (ft)	Flow (cfs)
A	100590	1330	13.6	8.0	9.0	0.89	50.0	2.4	4.21	0.25
B	100690	1400	13.2	NDR	NDR	NDR	46.0	2.6	4.15	0.31
C	111590	1418	3.5	4.0	6.2	0.65	20.0	11.8	3.84	5.07
D	111690	1400	4.1	4.2	6.3	0.67	22.0	10.5	3.86	5.22
E	041591	1520	8.2	NDR	NDR	NDR	22.0	NDR	4.36	NDR

Temp = temperature
DO = dissolved oxygen
µmho/cm = micromho per centimeter
NDR = not determined
Cond = conductivity
°C = celsius
mg/L = milligrams per liter

Table L-5

Summary of Water Quality and Quantity Data
Collected at Marshall Watershed, Site 1
Acadia National Park

MARSHALL WATERSHED

Site 1: Marshall Brook (East)

Run	Date	Time	Temp (°C)	Sodium (mg/L)	Chloride (mg/L)	Sodium/ Chloride	Cond (μmho/cm)	DO (mg/L)	Stage (ft)	Flow (cfs)
A	100590	1130	13.6	NDR	NDR	NDR	95.0	4.1	2.21	NDR
B	100690	1145	4.0	11.0	21.0	0.53	65.0	8.2	2.10	0.04
C	111590	1330	3.5	NDR	NDR	NDR	62.0	8.4	NDR	0.10
D	111690	0845	4.5	NDR	NDR	NDR	68.0	7.8	2.14	0.08
E	041591	1400	8.6	NDR	NDR	NDR	71.0	NDR	2.06	NDR

Temp = temperature

DO = dissolved oxygen

μmho/cm = micromho per centimeter

NDR = not determined

Cond = conductivity

°C = celsius

mg/L = milligrams per liter

Table L-6

Summary of Water Quality and Quantity Data
Collected at Marshall Watershed, Site 2
Acadia National Park

MARSHALL WATERSHED
Site 2: Marshall Brook (West)

Run	Date	Time	Temp (°C)	Sodium (mg/L)	Chloride (mg/L)	Sodium/ Chloride	Cond (μmho/cm)	DO (mg/L)	Stage (ft)	Flow (cfs)
A	100590	1130	13.6	13.0	21.5	0.61	102.0	5.9	1.68	0.32
B	100690	1140	2.3	5.7	9.6	0.59	55.0	10.2	1.47	0.96
C	111590	1330	4.7	10.0	17.2	0.58	65.0	9.3	1.48	0.78
D	111690	0830	4.3	10.0	17.2	0.58	65.0	8.2	1.49	0.66
E	041591	1410	8.1	NDR	NDR	NDR	59.0	NDR	1.46	NDR

Temp = temperature
DO = dissolved oxygen
μmho/cm = micromho per centimeter
NDR = not determined

Cond = conductivity
°C = celsius
mg/L = milligrams per liter

APPENDIX M

GWLF Users Manual.

GWLF

GENERALIZED WATERSHED LOADING FUNCTIONS

USER'S MANUAL

March 31, 1989

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TABLE OF CONTENTS

User's Manual for GWLF,
GENERALIZED WATERSHED LOADING FUNCTIONS

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. 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.

This manual describes a 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. The programs are available on two 5.25 inch floppy disks. The QuickBASIC programs are on Disk A and Disk B contains executable files (compiled versions) for these same programs. Although QuickBASIC 4.5 (or higher) must be installed on the computer in order to use and edit the programs on Disk A, the executable files can be run directly from DOS without using QuickBASIC. Associated data files and output for Example 1 from this manual are included on both disks. In addition, Disk A contains a 50-year weather record used for Example 3.

The main body of this manual describes the program structures and input and output files and options. Three example 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 wash-off functions. Constant daily rates of nutrient accumulation are assumed as functions of land use. 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.

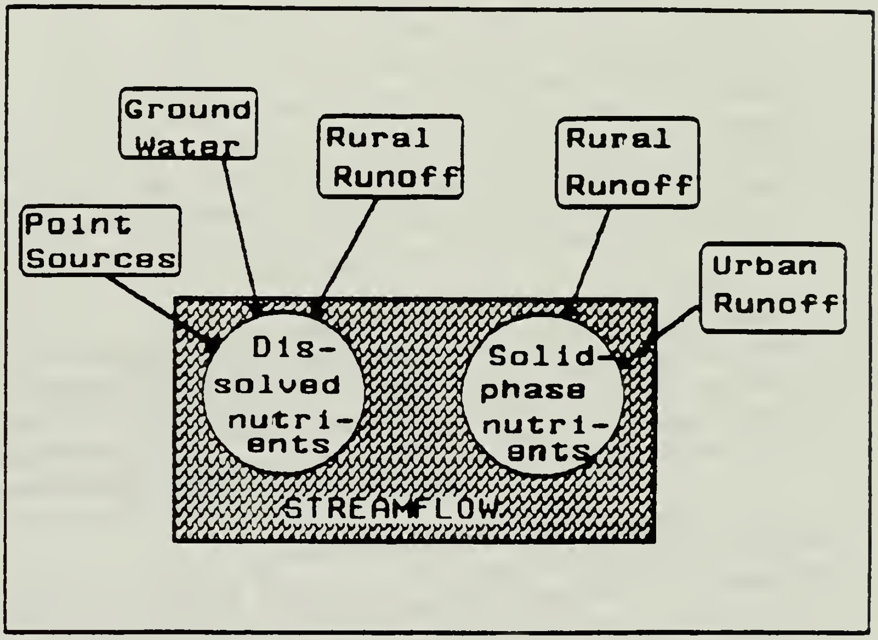


Figure 1. Nutrient Sources in GWLF.

Streamflow consists of runoff and discharge from ground water. 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 snow melt less runoff and evapotranspiration. Percolation occurs when unsaturated zone water exceeds field capacity. The shallow saturated zone is modeled as a linear ground water 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 ground water recession and seepage coefficients, 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 snow melt.

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. The remaining nutrient data are dissolved nitrogen and phosphorus concentrations in ground water.

Point sources of nitrogen and phosphorus are assumed to be in dissolved form and must be specified for each month.

Procedures for estimating transport and nutrient parameters are described in Appendix B. Sample estimates are also given in Appendix C and in the examples provided 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

GWLF PROGRAM

Required Files

Simulations by GWLF require program modules and three data files on the default drive. If the model is run from DOS, the three compiled modules, or executable files from Disk B (**GWLFQB.EXE**, **TRANQB.EXE** and **NUTRQB.EXE**) are used, and the run is initiated by typing **GWLFQB**. The uncompiled QuickBASIC versions of these modules are combined on Disk A as **GWLFQB.BAS**. The model is implemented from QuickBASIC by loading and running **GWLFQB.BAS** (with data files on the default drive). The three necessary data files for runs from either DOS or QuickBASIC are **WEATHER**.DAT, **TRANSPRT**.DAT and **NUTRIENT**.DAT.

Two weather files are included on the disks, **WEATH3Y.DAT** (Disks A & B) and **WEATH50Y**.DAT (Disk A). The first of these is a 3-year record used in Examples 1 and 2 and the second is the 50-yr record for Example 3. Prior to running the programs, the appropriate weather record should be copied to **WEATHER.DAT**. The final two files on the disks (**RESULTS**.DAT, and **SUMMARY.DAT**) are output files from Example 1.

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.

```
 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.

The selection of the menu options is done by typing the number indicating a choice and then *Enter*. For example, selection of Run simulation is done by typing *3* and *Enter*.

Transport Data Manipulation

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

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

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

Create a New TRANSPRT.DAT File. New values of transport parameters are expected to be 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 *Esc*, then *Enter*. Alternatively, the user may save current input and modify the data in the modification mode.

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.

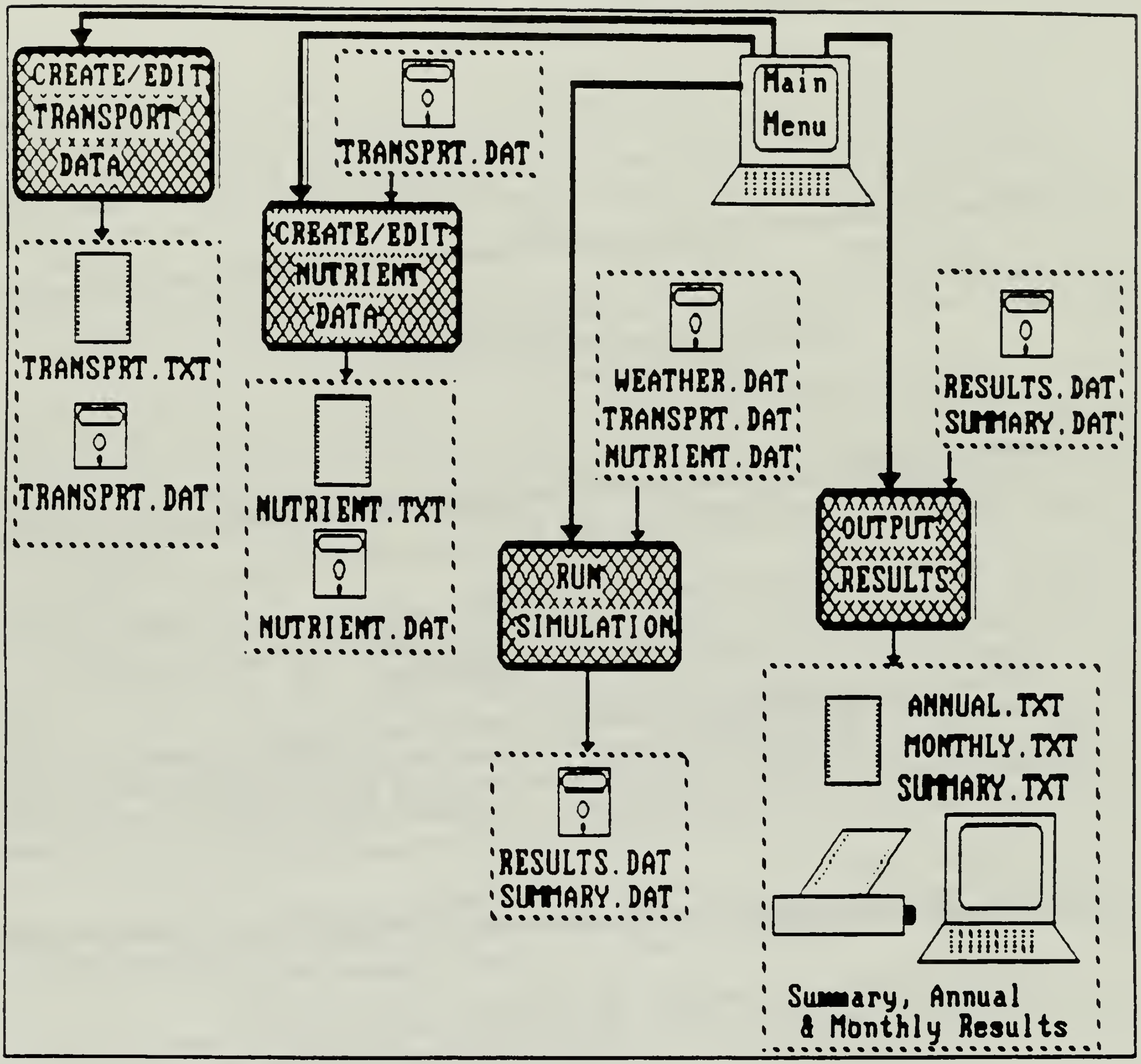


Figure 2. Structure of the GWLF Program.

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

Three categories of simulation can be performed, as shown in DISPLAY 4. To

```
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
  otherwise   Return
?
```

DISPLAY 4. The Menu Page for Simulation Options.

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.

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

Results Output

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

EXAMPLE 1: 3-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 Mew York.

```
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.

This example uses the compiled program modules and associated data files given on Disk B and is run directly from DOS. The programs **GWLFQB.EXE**, **TRANQB.EXE** and **NUTRQB.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 **WEATH3Y.DAT** to **WEATHER.DAT**.

Simulation

To start the program, type *GWLFQB* 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 are of interest, type *3* 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 *3*, then *Enter*. This concludes the information required for a simulation run. The input section described above is shown in DISPLAY 6.

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

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.

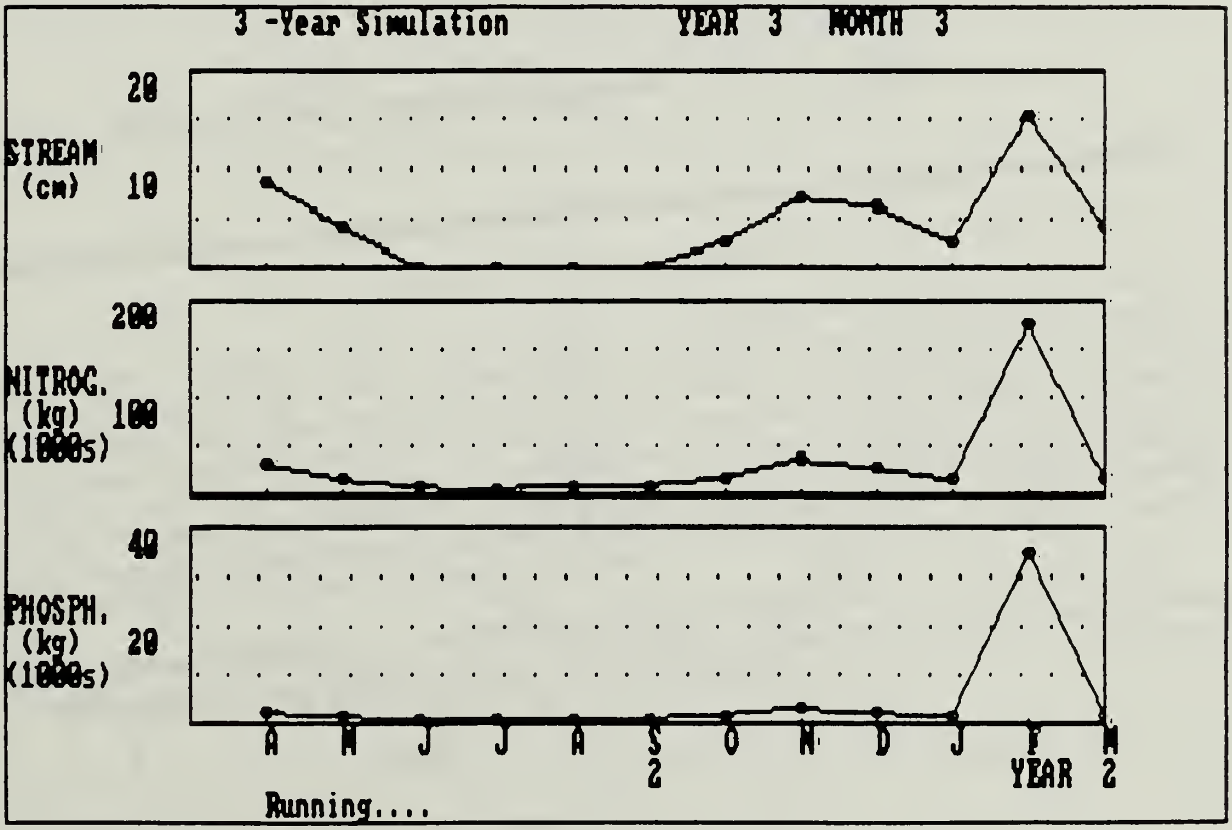
The user decides on the type of output. Type *1*, then *Enter* to print to the

```
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
  otherwise   Return
? 3

TITLE OF SIMULATION? Example 1
LENGTH OF RUN IN YEARS? 3
```

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



3 -Year Simulation   YEAR 3   MONTH 3

Running....

Figure 3. Screen Display during Simulation.

```
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.

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 D with the various **.TXT** files that may be generated.

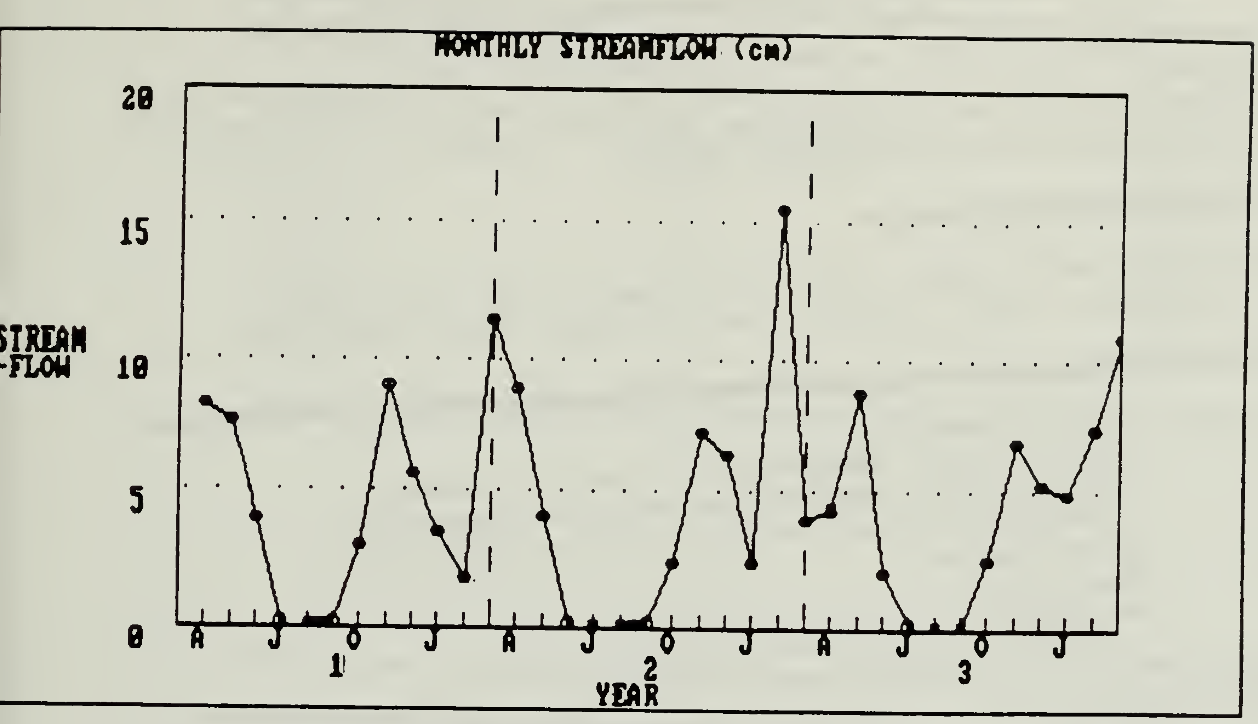


Figure 4. Monthly Streamflows for Example 1.

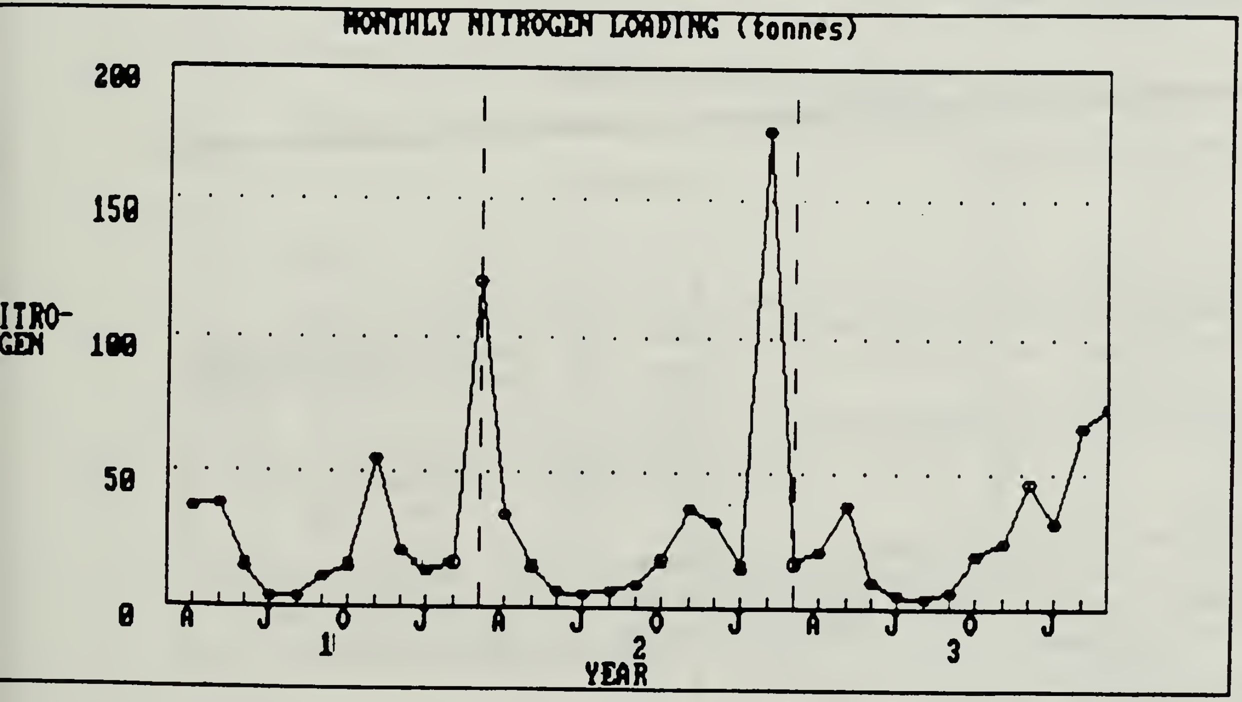


Figure 5. Monthly Nitrogen Loads for Example 1.

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).

```
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.

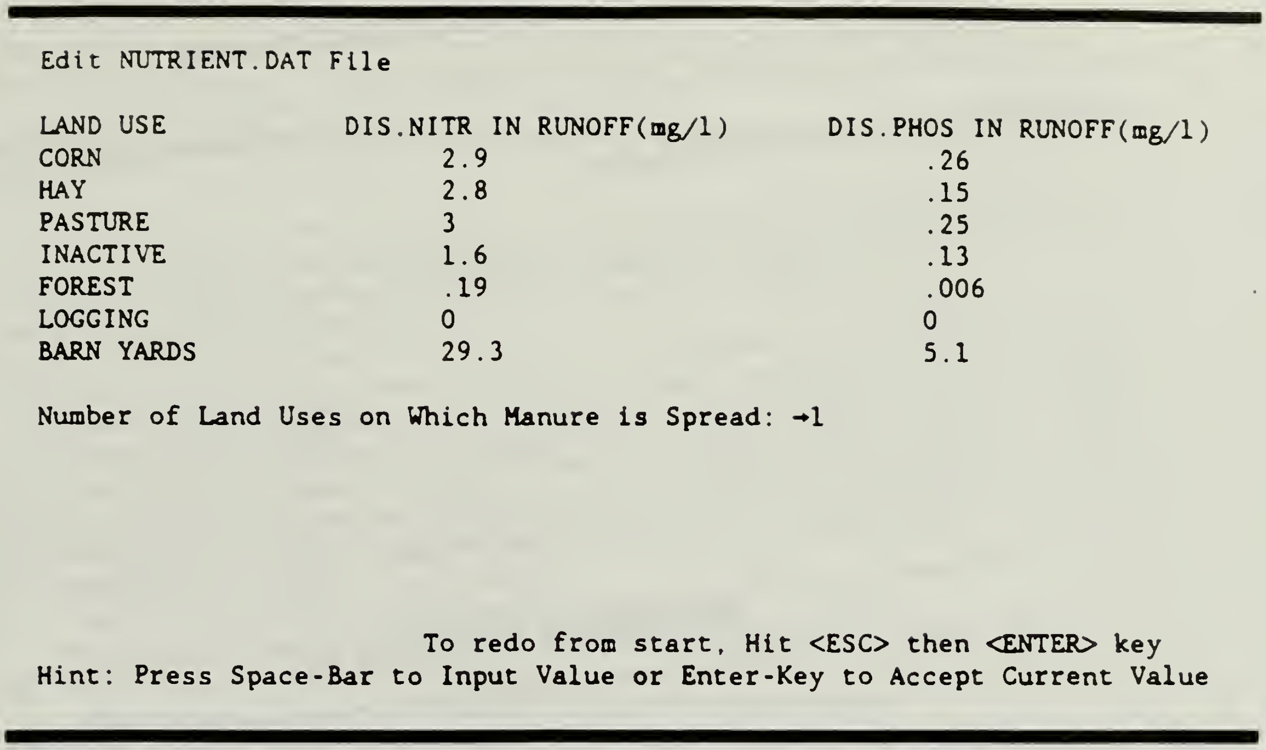
Type *Enter* to accept the original dissolved nutrient concentrations. Repeat this procedure until the cursor is in the line, Number of Land Uses on Which Manure is Spread (see DISPLAY 9), hit *Space-bar*, type *0*, and hit *Enter*.

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.

Simulation and Results Generation

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



```
Edit NUTRIENT.DAT File

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

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




                        To redo from start, Hit <ESC> 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.

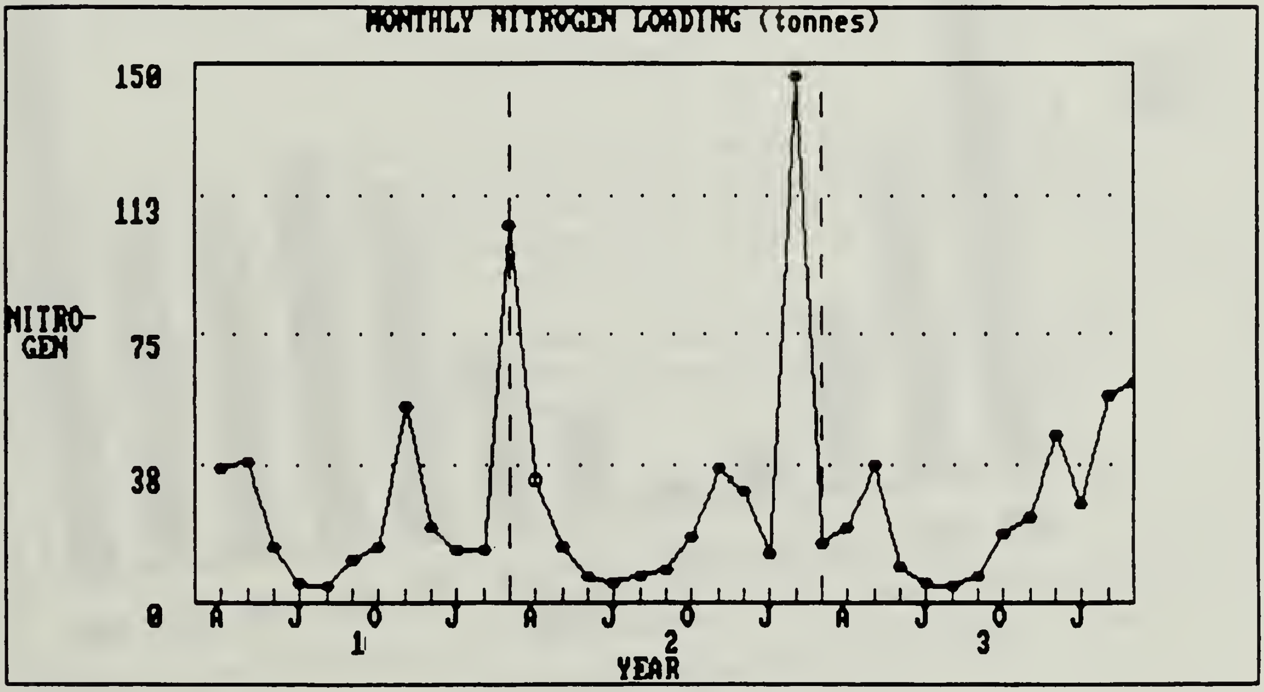


Figure 6. Monthly Nitrogen Loads with no Manure Spreading.

EXAMPLE 3: A 50-YEAR SIMULATION STUDY

In Example 3, a simulation of the West Branch Delaware River Basin is based on a 50-yr weather record given in the file **WEATH50Y.DAT** on Disk A.

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 *50* and then *Enter*. A 50-year simulation takes roughly 15 minutes on an IBM PC/AT with a 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.

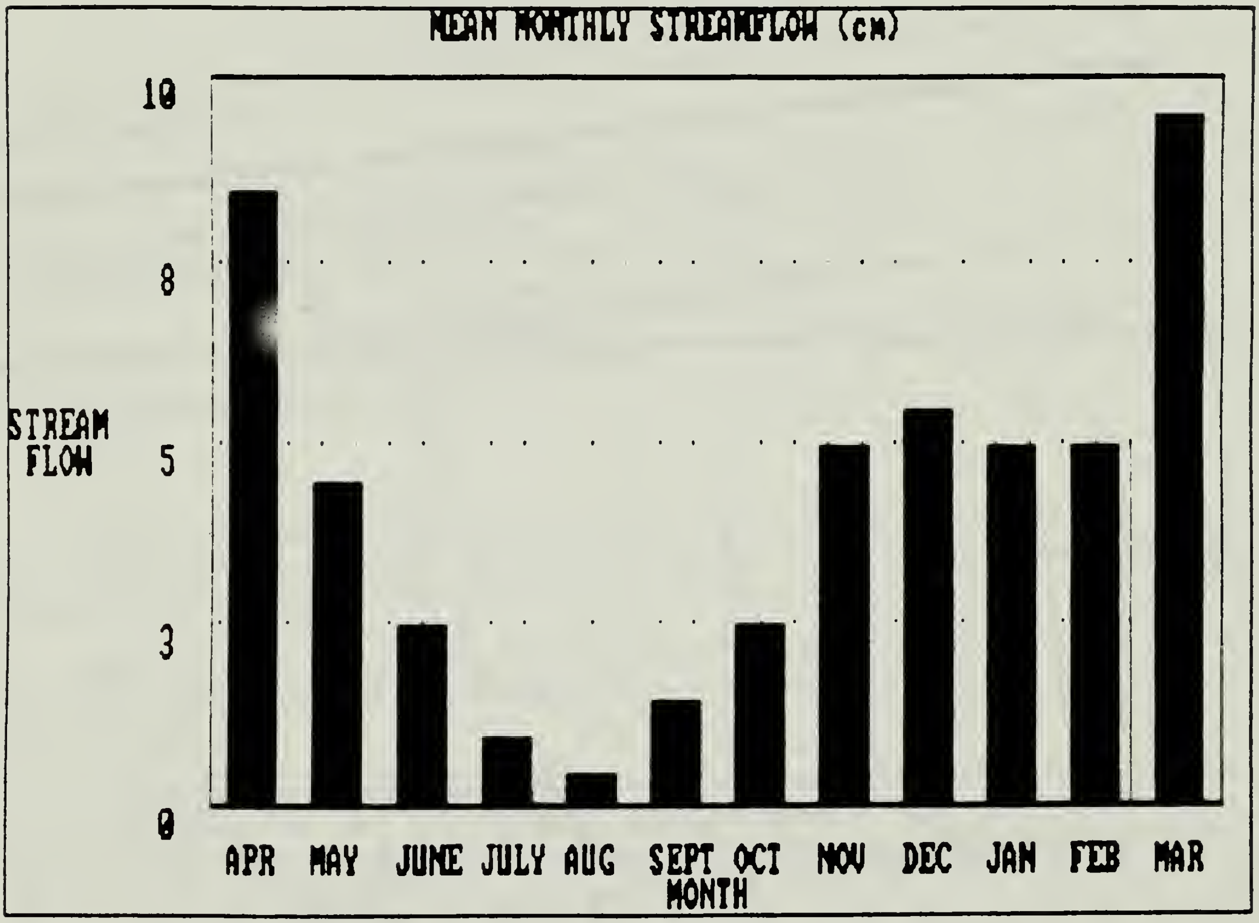


Figure 7. Mean Monthly Streamflow for Example 3.

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

```
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

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 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.

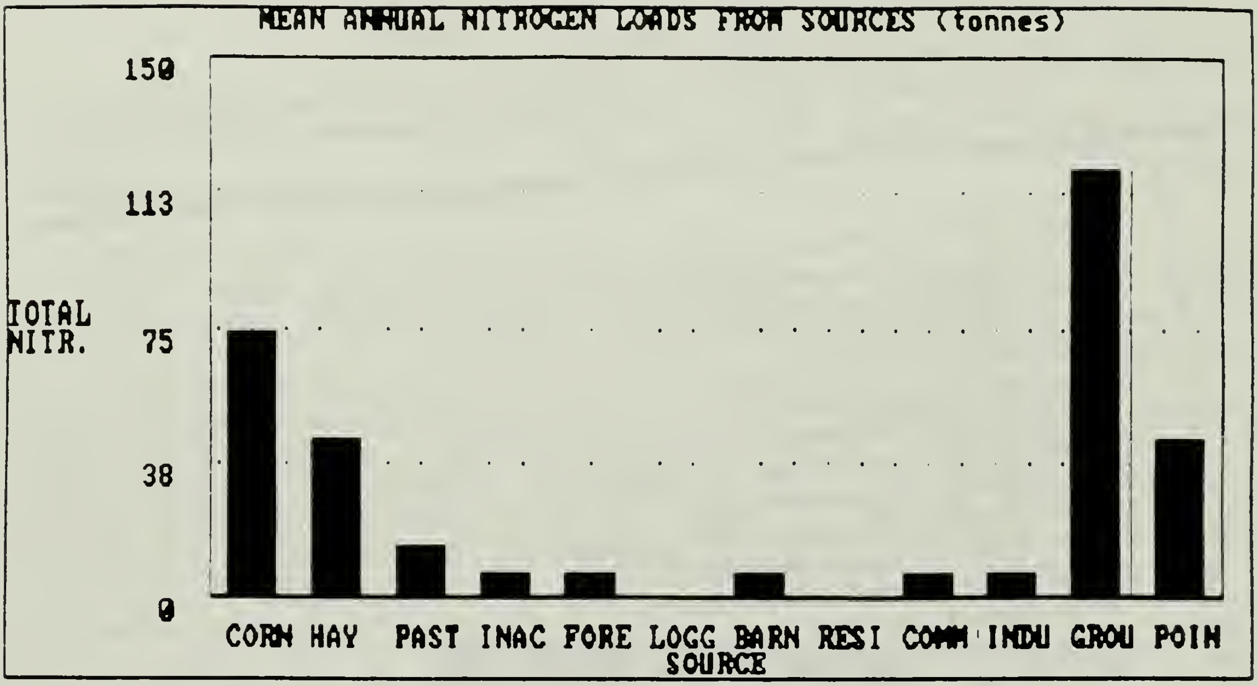


Figure 8. Mean Annual Nitrogen Load from Sources.

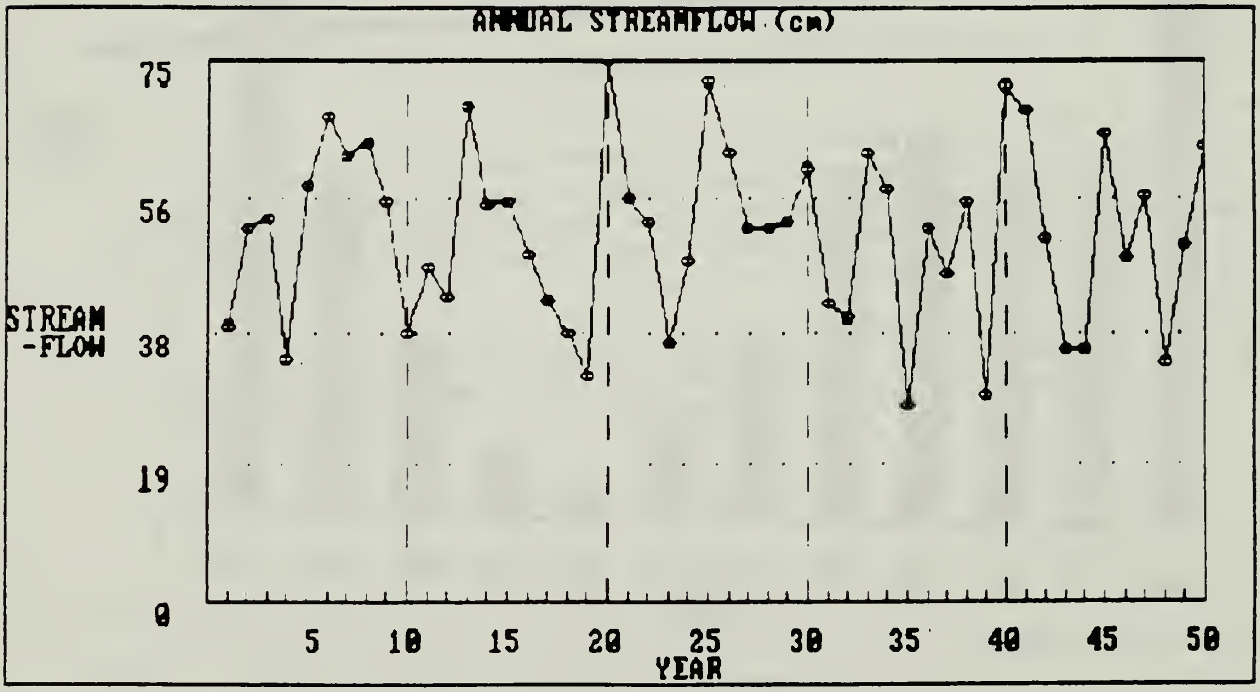


Figure 9. Annual Streamflows for Example 3.

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 are

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

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

In these equations, LD_m is dissolved nutrient load, LS_m is solid-phase nutrient load, DP_m, DR_m, DG_m and DU_m are point source, rural runoff, groundwater and urban runoff 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, respectively, in month m (kg).

Rural Runoff

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 from daily weather data by the U.S. Soil Conservation Service's Curve Number Equation (Ogrosky & Mockus, 1964). Thus Q_{kt}, runoff from source area k on day t (cm), is given by

$$Q_{kt} = \frac{(R_t + M_t - 0.2\ W_t)^2}{R_t + M_t + 0.2\ M_t} \qquad \text{(A-3)}$$

Rainfall R_t (cm) and snow melt 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. Snow melt water is computed by a degree-day equation (Haith, 1985):

$$M_t = 0.45\ T_t,\ \text{for}\ T_t > 0 \qquad \text{(A-4)}$$

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

$$W_{kt} = \frac{2540}{CN_{kt}} - 25.4 \qquad \text{(A-5)}$$

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):

$$A_t = \sum_{n=t-5}^{t-1} (R_n + M_n) \qquad \text{(A-6)}$$

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. Growing and dormant seasons are designated based on mean daily air temperature, with dormant months being those with mean temperatures below 10 °C. For snow melt conditions, it is assumed that the wettest antecedent moisture conditions prevail and hence regardless of A_t, $CN_{kt} = CN3_k$ when $M_t > 0$.

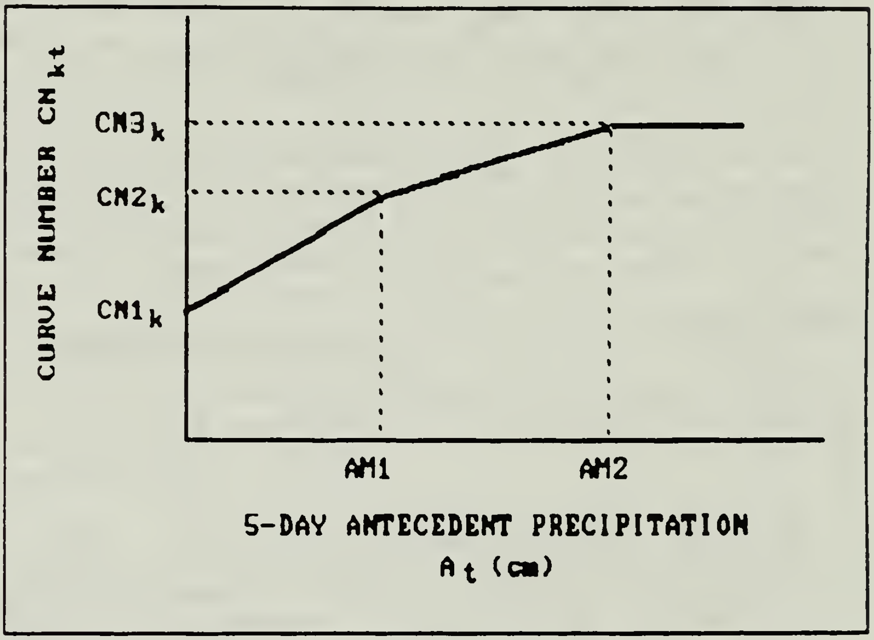


Figure A-1. Curve Number Selection as Function of Antecedent Moisture.

Dissolved nutrient load from the source area on day t is obtained by multiplying Q_{kt} by the dissolved nitrogen or phosphorus concentration and the area of the source. Total dissolved nutrient load for the month (DR_m) is computed by summing over all sources and days of the month.

Solid-phase rural nutrient loads (SR_m) are given by the product of monthly sediment yields and average sediment nutrient concentrations. Sediment yields are computed by the model given by Haith (1985). In that model, sediment is generated by erosion from rural source areas using the Universal Soil Loss Equation (Wischmeier & Smith, 1978) with the daily rainfall erosivity index developed by Richardson <u>et al</u>. (1983). Sediment yield is the product of erosion and a sediment delivery ratio, and the yield in any month is proportional to the total transport capacity of daily runoff during the month.

Urban Runoff

The urban runoff component of the GWLF follows the structure of the U. S. Army Corps of Engineers' model STORM (Hydrologic Engineering Center, 1977), but operates with a daily time step. Since STORM considers nutrient mass to be associated with accumulated solids, urban nutrient loads are assumed to be entirely solid-phase ($DU_m = 0$ in Equation A-1). Nutrients accumulate on each urban land use at a constant daily rate. Runoff is determined by the Curve Number Equation.

Nutrient accumulation on urban land use k at the beginning of day t+1 (kg) is given by

$$N_{k,t+1} = N_{kt} + n_k - QN_{kt} \qquad \text{(A-7)}$$

where n_k is the daily buildup of nutrient on land use k (kg/day) and QN_{kt} is the nutrient removal by runoff (kg) on day t. This removal is

$$QN_{kt} = w_{kt} \, (N_{kt} + n_k) \qquad \text{(A-8)}$$

The rate coefficient w_{kt} is described by the wash-off function given in Amy *et al*. (1974):

$$w_{kt} = 1 - \exp(-1.81 \, Q_{kt}) \qquad \text{(A-9)}$$

Total dissolved urban nutrient load for the month (DU_m) is computed by summing over all sources and days of the month.

Groundwater Sources

Groundwater discharge to the stream is described by the lumped parameter model shown in Figure A-2. Streamflow consists of total watershed runoff plus groundwater discharge from a shallow saturated zone. The division of soil moisture into unsaturated, shallow saturated and deep saturated zones is similar to that used by Haan (1972).

Daily water balances for the unsaturated and shallow saturated zones are

$$U_{t+1} = U_t + R_t + M_t - Q_t - E_t - PC_t \qquad \text{(A-10)}$$

$$S_{t+1} = S_t + PC_t - G_t - D_t \qquad \text{(A-11)}$$

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).

Runoff (Q_t) is the sum of runoff from all rural and urban sources. Evapotranspiration is given by

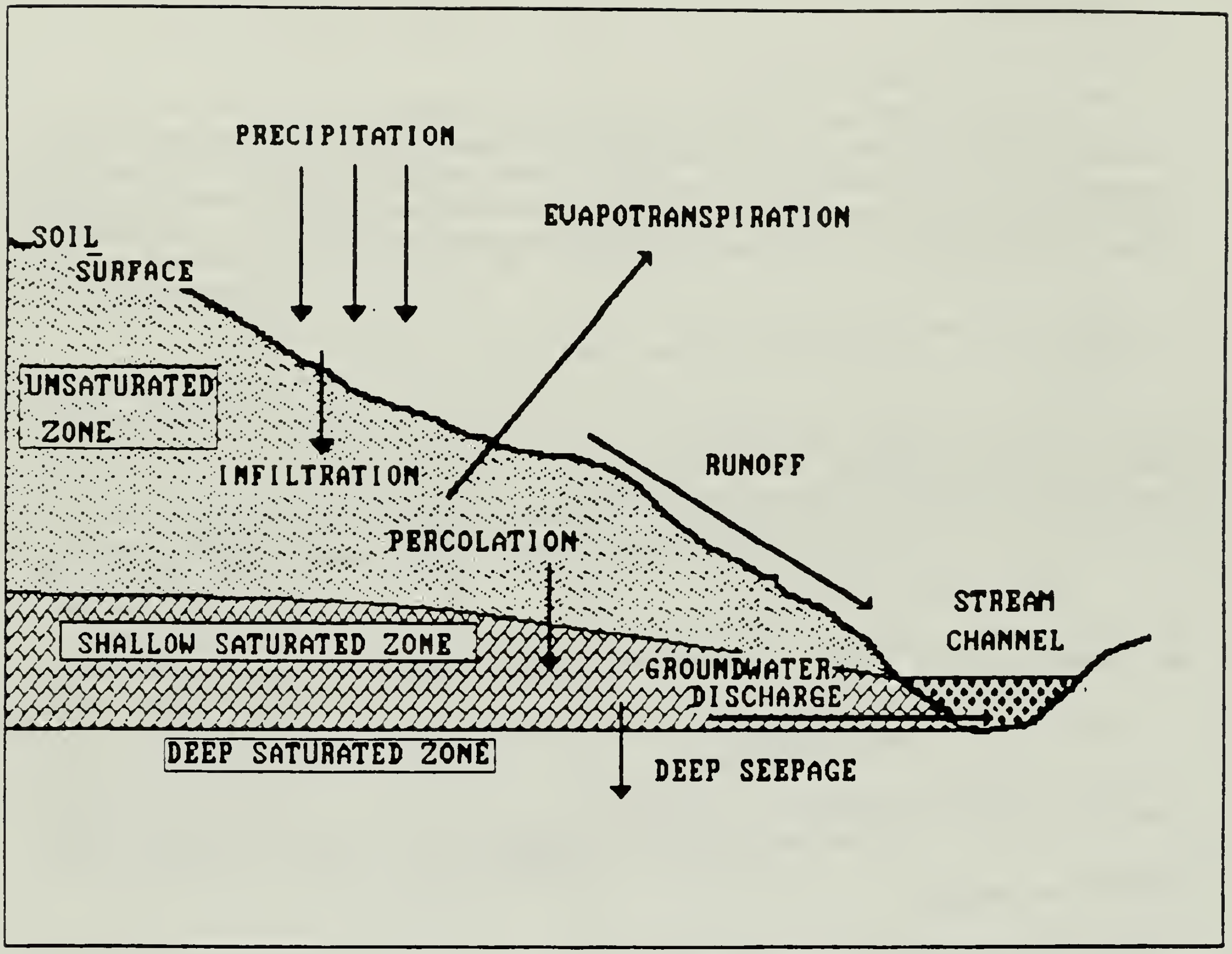


Figure A-2. Lumped Parameter Model for Ground Water Discharge.

$$E_t = CV_t \, PE_t \tag{A-12}$$

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

$$PE_t = (0.021 \, H_t^2 \, e_t)/(T_t + 273) \tag{A-13}$$

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 $T_t \le 0$, PE_t is set to zero.

Percolation occurs when unsaturated zone water exceeds field capacity. If U_t is normalized so that $U_t = 0$ corresponds to field capacity, then

$$PC_t = \text{Max}\ (0;\ U_t + R_t + M_t - Q_t - E_t) \tag{A-14}$$

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

$$G_t = r\ S_t \tag{A-15}$$

nd

$$D_t = s\ S_t \tag{A-16}$$

here r and s are ground water recession and seepage constants, respectively lay^{-1}).

The mass load of dissolved nutrient in groundwater discharge (DG_m in uation A-1) is obtained by multiplying total groundwater discharge for the nth by the average nutrient concentration in groundwater.

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.

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 the watershed unsaturated zone is at field capacity and runoff events have "flushed" the watershed of the previous year's accumulated sediment. In the eastern U.S. this generally occurs in late spring and hence in such locations an April - March weather year is appropriate.

Transport Parameters

Hydrologic, erosion and sediment parameters required for the data file **TRANSPRT.DAT** are listed in Appendix D.

Hydrology. Runoff curve numbers for rural and urban land uses are available in several general references (Bureau of Reclamation, 1973; Mockus, 1972; Ogrosky & Mockus, 1964; Soil Conservation Service, 1975). Since the GWLF program calculates curve numbers for antecedent moisture conditions 1 and 3, only the curve numbers for condition 2 ($CN2_k$) must be specified. 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 ~~may be determined from~~ published seasonal values (Davis & Sorensen, 1969; Novotny & Chesters, 1981; U.S. Forest Service, 1980; Lull, 1968).

The groundwater portion of GWLF requires estimates of initial unsaturated zone and shallow saturated zone moisture levels (U_1 and S_1, respectively) and recession and seepage constants (r and s, respectively). Since the simulation year starts at a time when the watershed is wet, and U_t is normalized so that $U_t = 0$ corresponds to field capacity, U_1 may be set to zero.

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

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

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.

Equation B-2 can be used to estimate the initial S_t (S_1) for model runs. The nearest recession to the simulation starting date (April 1 in the applications in this manual) is identified, Equation B-2 is solved for S(0) and $S_1 = S(0)$. Alternatively, since the effect of S_1 is dampened out after several months of simulation, an arbitrary value may be selected for S_1 and the first year of simulation results can be discarded.

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, LS, C and P for the Universal Soil Loss Equation must be specified as the product K•LS•C•P for each rural runoff source area. Values of these four parameters are given in standard references and manuals (Mills et al., 1985; Novotny and Chesters, 1985; Stewart et al., 1985; Wischmeier & Smith, 1978). Also required are values of the seasonal coefficient "a" for the Richardson et al. (1983) rainfall erosivity relationship. Values have been determined for the 11 locations given in Table B-1, and the coefficients corresponding to the site closest to the simulation location should be selected. Watershed sediment delivery ratios are most commonly obtained from the area-based relationship shown in Figure B-1 (Vanoni, 1975).

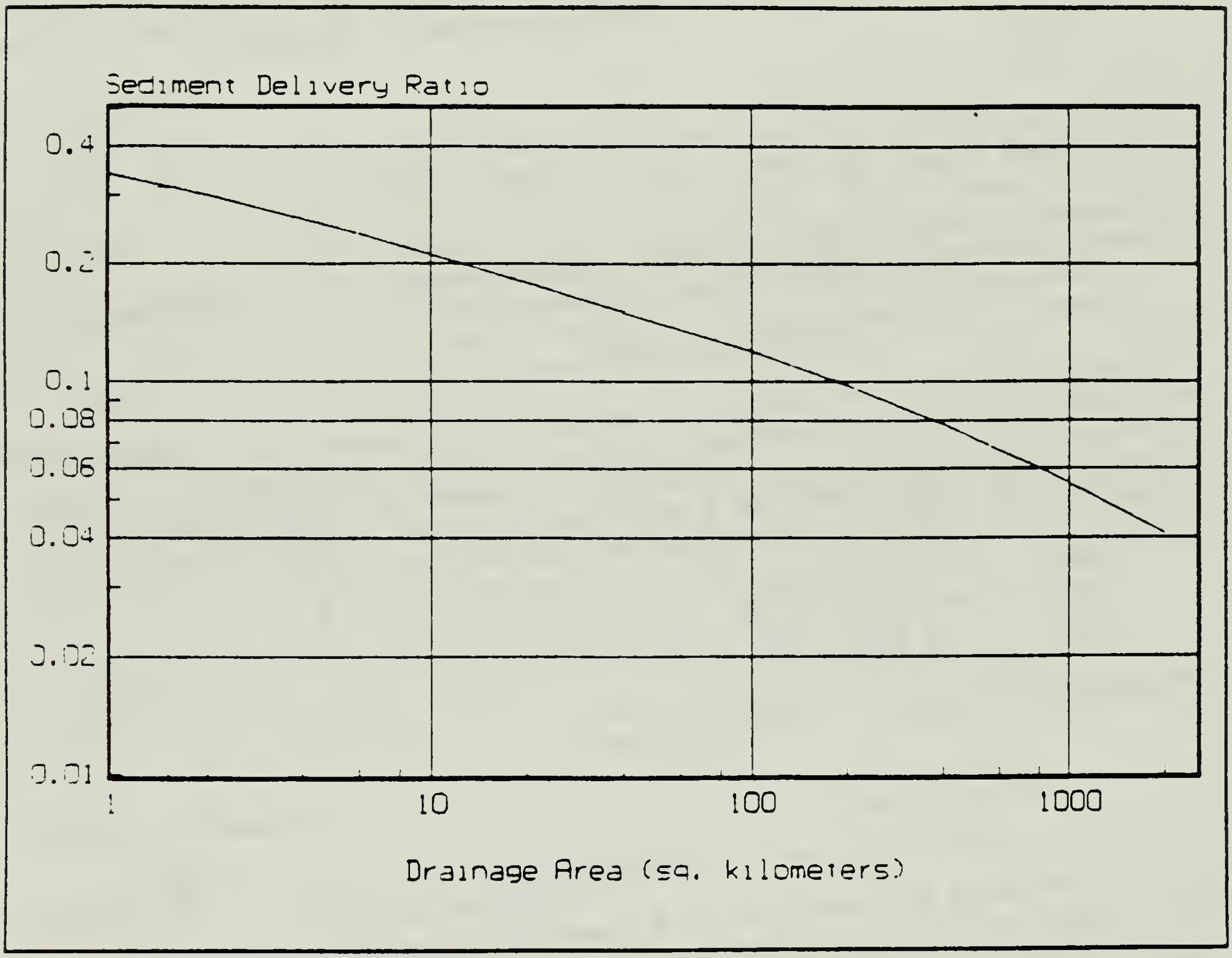


Figure B-1. Watershed Sediment Delivery Ratios.

Location	Cool Season (Oct-Mar)	Warm Season (Apr-Sept)
Blacksburg VA	.11	.45
Cherokee OK	.36	.49
Hastings NE	.18	.40
Hays KS	.16	.34
Ithaca NY	.09	.34
Lansing MI	.11	.24
Madison WI	.11	.31
Riesel TX	.27	.44
State College MS	.21	.51
Tifton GA	.32	.56
Urbana IL	.14	.34

Table B-1. Values of Rainfall Erosivity Coefficient for 11 Locations (Richardson *et al.*, 1983).

Nutrient Parameters

Parameters required for the data file **NUTRIENT.DAT** are listed 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.

Default values for urban nutrient accumulation rates are provided in the STORM users' manual and are duplicated in Table B-2. Solid-phase nutrients in sediment from rural sources can be estimated as the average soil nutrient

Land Use	Nitrogen	Phosphorus
	--------(kg/ha)----------	
Low Density Residential[a/]	0.008	0.0015
Medium Density Residential[a/]	0.031	0.0023
High Density Residential[a/]	0.028	0.0073
Commercial	0.237	0.0146
Industrial	0.234	0.0110

[a/] Density measured in dwelling units/ha: low, 5-12; medium, 12-25; high, >25.

Source: Hydrologic Engineering Center (1977)

Table B-2. Daily Urban Nutrient Accumulation Rates.

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 McElroy et al. (1976) and Mills et al. (1985). 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; Haith & Tubbs, 1981; Mills et al., 1985).

Default flow-weighted mean concentrations of dissolved nitrogen and phosphorus in agricultural runoff are given in Table B-3. 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 snow melt 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).

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
Snow melt 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-3. Dissolved Nutrients in Agricultural Runoff.

Default values for nutrient concentrations in groundwater discharge can be obtained from the U.S. Eutrophication Survey results (Omernik, 1977) given in Table B-4. 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.

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
Source: U. S. National Eutrophication Survey (Omernik, 1977)

Table B-4. Mean Dissolved Nutrients in Streamflow.

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-4 as estimates of runoff concentrations.

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 850 km^2 watershed, which is shown in Figure C-1, is in a New York dairy farming area 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 three-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.

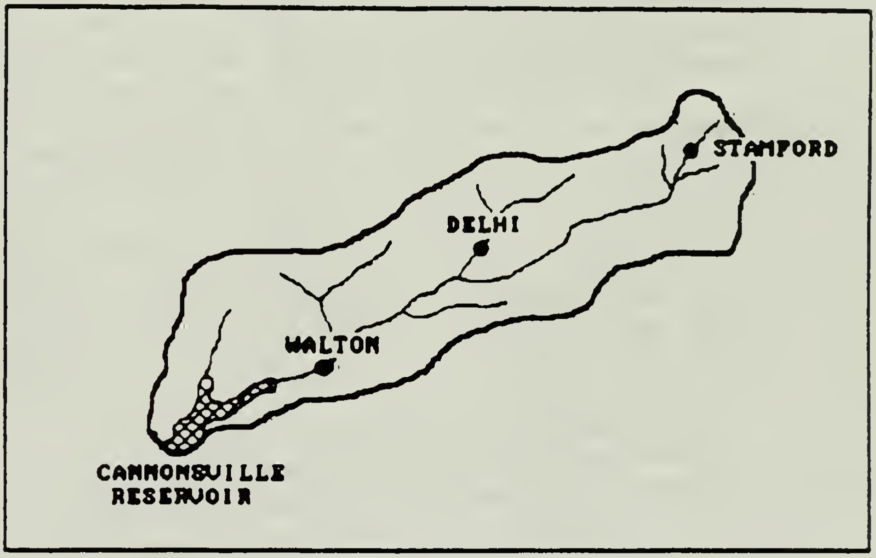


Figure C-1. West Branch Delaware River Watershed.

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 snow melt 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 sample falling in forested areas, the following parameters were recorded: land use (brushland or mature forest), soil type and the position of the sample on the slope. The latter characteristic was used in combination with land use to determine the depth of the humus layer. Humus depth in the watershed was estimated as 2.5-5.0, 10-13 and 2.5 cm for hill tops, valleys and slopes, respectively (personal communication, F. Gilbert, U.S. Soil Conservation Service, Syracuse, NY). Humus depth for forest brushland was estimated as 0-2.5 cm, and all humus layers were described as definitely not firm or felty. Middle values of these ranges were used in the procedure to determine curve numbers.

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.

Runoff Curve Numbers. In forest areas, curve numbers were determined from the soil type and humus depth (Bureau of Reclamation, 1973). Agricultural curve numbers were selected based on soil type, crop, management practice (contoured, straight rows, etc.) and hydrologic condition from Ogrosky & Mockus (1964). 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).

Agricultural 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.

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	66
	C	24693	76
	D	510	82
Mature Forest			
Slopes	C	23203	73
Hill Tops	C	2607	70
Slope/Valley	C	510	67
Valleys	B	510	51
	C	1531	61

a/ Antecedent moisture condition 2 ($CN2_k$)

Table C-1. Areas and Curve Numbers for Agricultural and Forest Runoff Sources.

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	73.3	--
Logging Trails	20	--	0.217
Residential (Low Density)	650	77.8	--
Commercial	90	89.3	--
Industrial	101	85.5	--

[a] Antecedent moisture condition 2 ($CN2_k$).
[b] K•LS•C•P

Table C-2. Aggregated Runoff Source Areas.

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, LS, C and P, and from this information an average K•LS•C•P value was calculated.

Soil erodibility factors (K) for agricultural land were obtained from the Soil Conservation Service. Cover factors (C) were selected from Stewart et al. (1975) 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•LS•C•P values are given in Table C-2. Coefficients for daily rainfall erosivity were selected from Table B-1 for the nearest location (Ithaca, NY). A watershed sediment delivery ratio of 0.065 was determined from Figure B-1.

Other Transport Parameters. For purpose of curve number selection, the growing season was assumed to correspond to months during which mean air temperature is at least 10°C (May-October). Area-weighted evapotranspiration cover coefficients for January - December are 0.49, 0.51, 0.51, 0.51, 0.85, 0.98, 1.00, 1.02, 1.03, 1.01, 0.50 and 0.44, respectively. An average ground water 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.

Nutrient Parameters. Using the default soil nutrient values and enrichment ratio described in Appendix B, sediment nutrient concentrations of 3000 mg/kg nitrogen and 1300 mg/kg phosphorus were estimated. Other nonpoint source nutrient data were selected from Tables B-2, B-3 and B-4. Manure is spread on corn land in the watershed and hence the manured land concentrations were used for corn land runoff in snow melt months (January - March). Inactive agricultural land was assumed to have nutrient concentrations midway between pasture and forest values.

Point sources of nutrients are dissolved loads from five municipal and two industrial wastewater treatment plants (solid-phase point sources are not significant). These inputs are 3800 kg/mo nitrogen and 825 kg/mo phosphorus (Brown & Rafferty, 1980; Dickerhoff, 1981).

Validation Results

The GWLF streamflow predictions are compared with observations in Figure

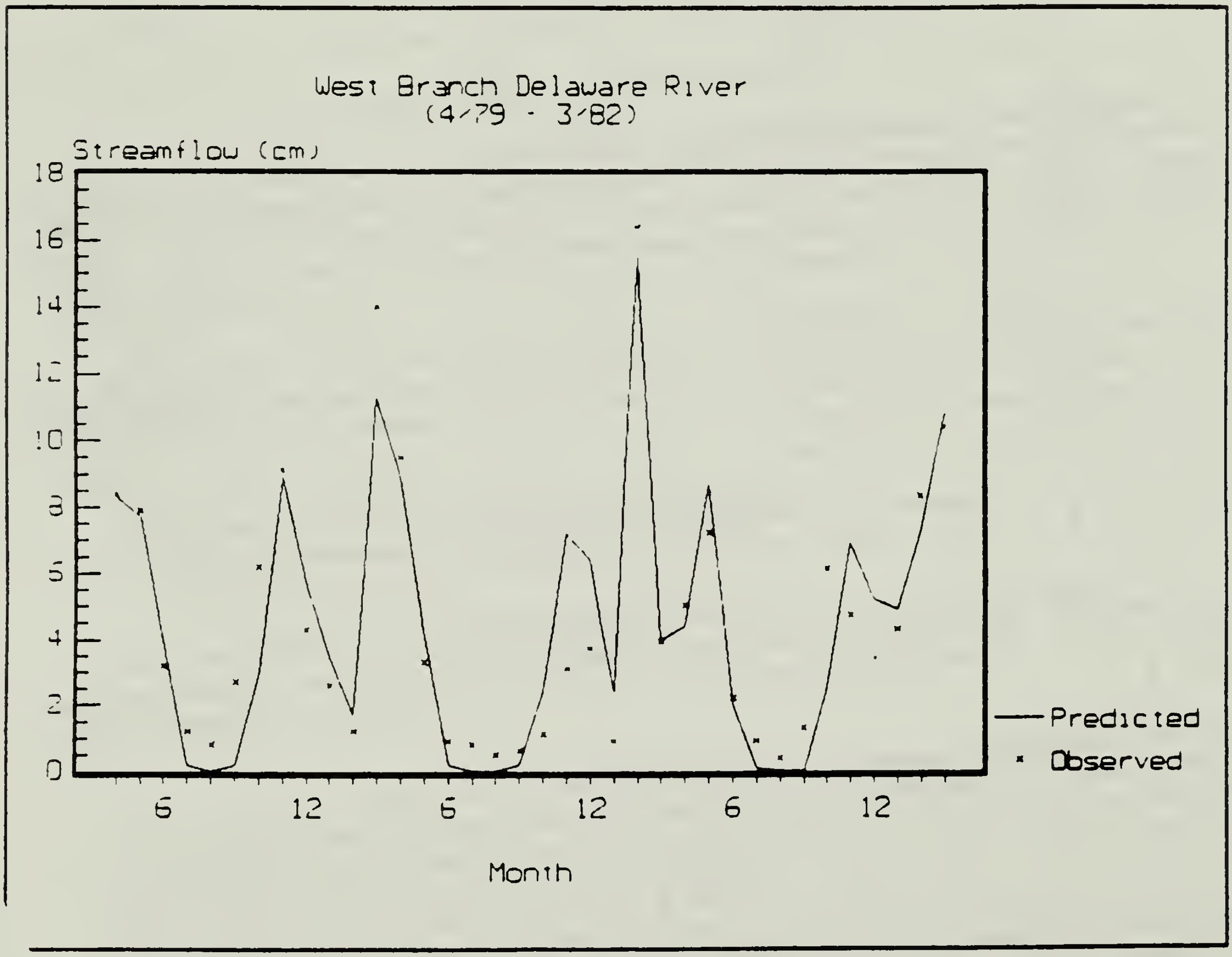


Figure C-2. Observed and Predicted Monthly Streamflow.

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

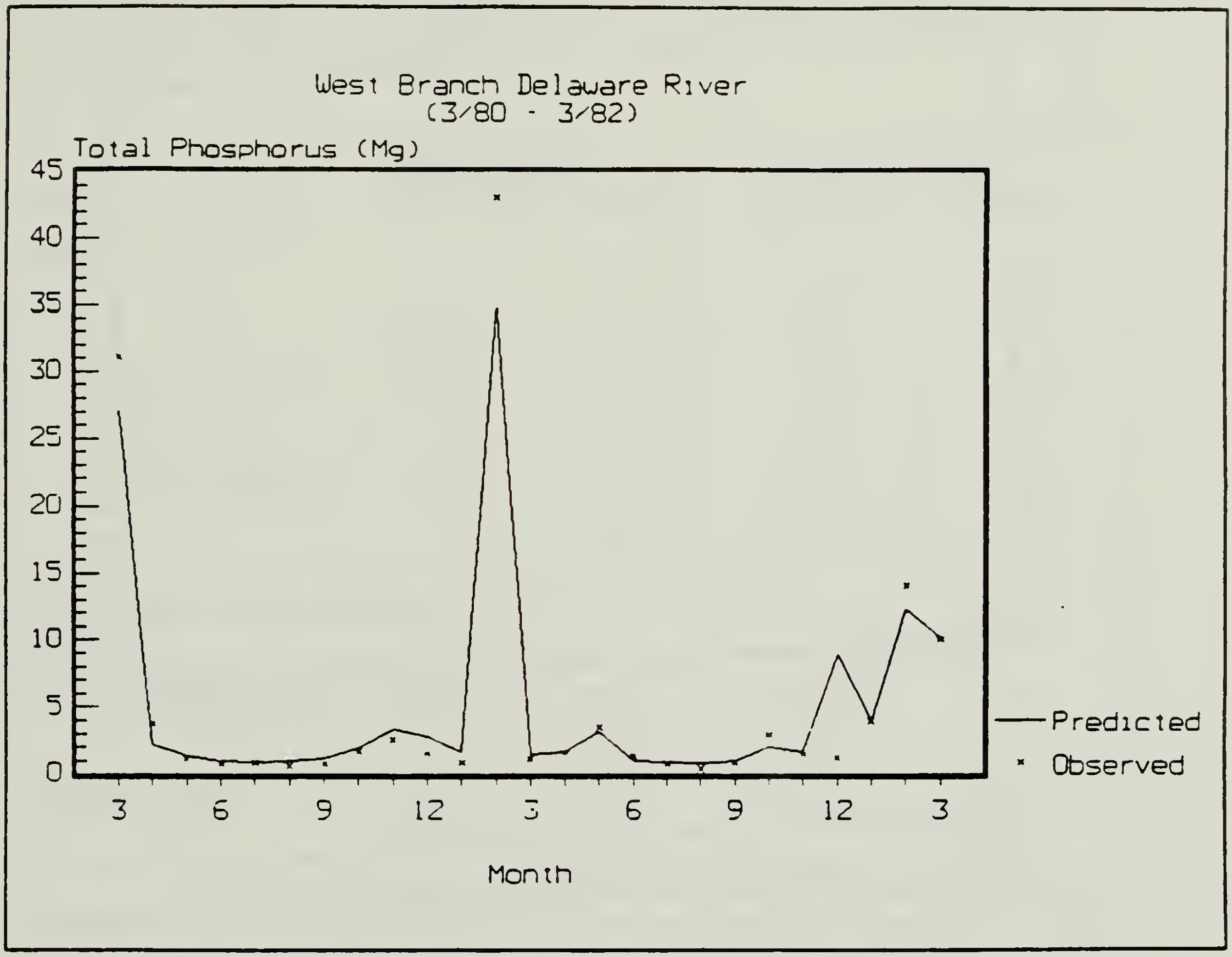


Figure C-3. Observed and Predicted Total Phosphorus in Streamflow.

Model predictions and observations for total phosphorus and nitrogen are compared in Figures C-3 and C-4. Both sets of predictions match the variations in observations but under-predict the February, 1981 peak values by 19% and 22% for phosphorus and nitrogen, respectively.

A quantitative summary of the comparisons of predictions with observations is given in Table C-3. Monthly mean predictions are within 20% of observation means for five of the six model outputs. The predicted mean total nitrogen flux is 72 % of the observed mean. With the exception of streamflow, no coefficient of determination (R^2) is less than 0.90, indicating that the model explains at least 90% of the observed monthly variation in sediment yield and total and dissolved nutrient fluxes.

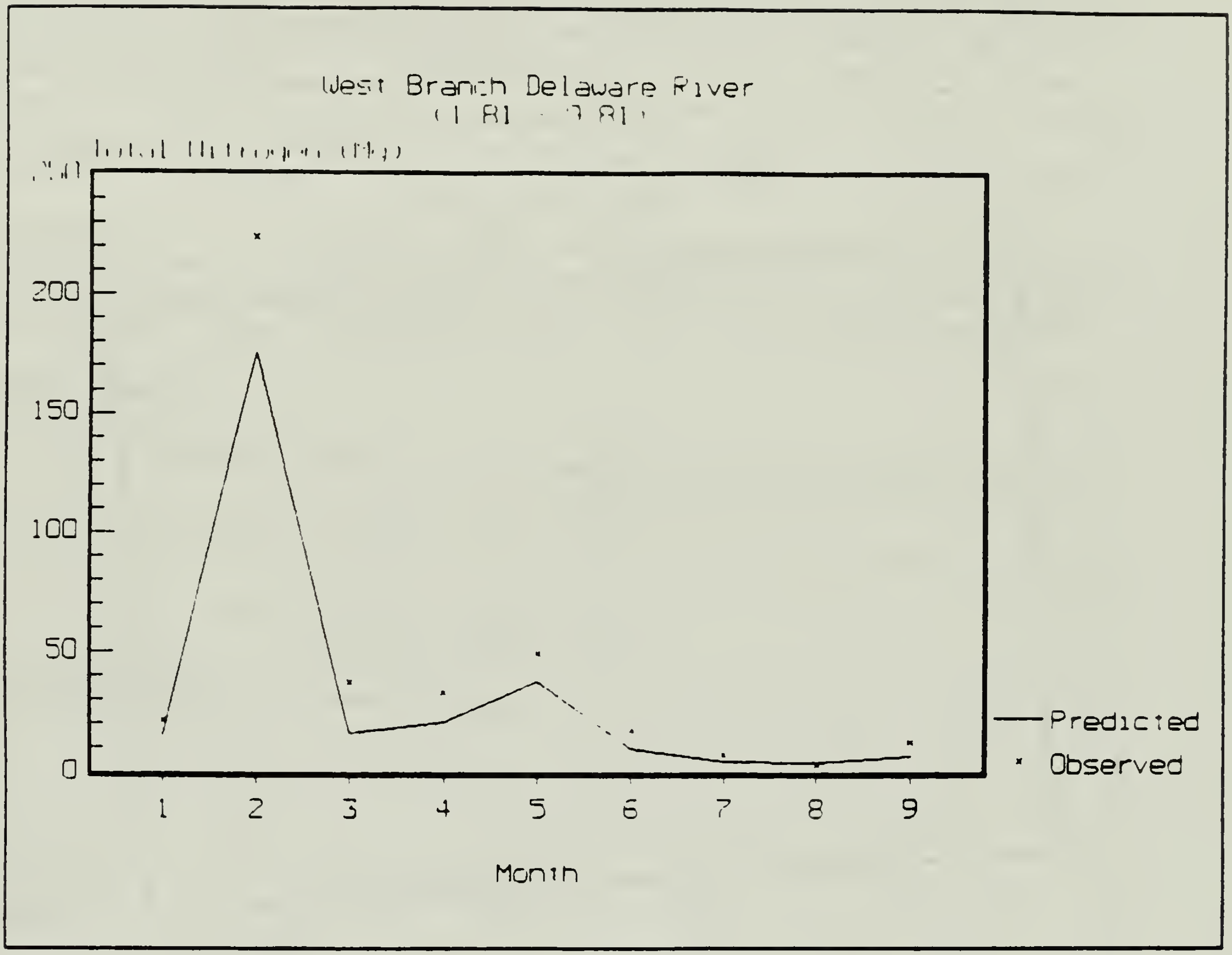


Figure C-4. Observed and Predicted Total Nitrogen in Streamflow.

Constituent	Validation Period	Monthly Means Predicted	Observed	Coefficient of Determination
Stream-flow (cm)	4/79-3/82	4.4	4.5	0.84
Sediment (1000Mg)	3/80-3/82	2.1	1.7	0.95
Nitrogen (Mg)				
Dissolved	3/80-9/81	22.8	27.8	0.90
Total	1/81-9/81	32.1	44.8	0.99
Phosphorus (Mg)				
Dissolved	3/80-3/82	2.3	2.4	0.91
Total	3/80-3/82	5.1	5.2	0.96

Table C-3. Comparison of GWLF Predictions and Observations for the W. Branch Delaware River Watershed.

Mean annual nutrient loads from each source for the three-year period are provided in Table C-4. 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 46% of dissolved and 36% of total nitrogen loads. Point sources constitute 13% of total nitrogen and 19% of total phosphorus.

Source	Nitrogen (Mg) Dissolved	Nitrogen (Mg) Total	Phosphorus (Mg) Dissolved	Phosphorus (Mg) Total
RUNOFF				
Corn	39.4	80.6	5.7	23.5
Hay	38.6	47.4	2.1	5.9
Pasture	10.2	14.8	0.8	2.8
Inactive Agriculture	3.9	7.4	0.3	1.9
Forest & Logging	7.3	7.5	0.2	0.3
Barn Yards	3.7	3.7	0.6	0.6
Urban	--	18.2	--	1.4
GROUNDWATER & POINT SOURCES				
Groundwater Discharge	127.1	127.1	5.0	5.0
Point Sources	45.6	45.6	9.9	9.9
WATERSHED TOTAL	275.8	352.3	24.6	51.3

Table C-4. Mean Annual Nutrient Loads Estimated from GWLF for the W. Branch Delaware River Watershed: 4/79 - 3/82.

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 22%. 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 a widely used model (STORM), model performance in more urban watersheds is uncertain.

APPENDIX D: DATA AND OUTPUT LISTINGS FOR 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. These files are also provided on Disks A and B. The first two files are constructed by selecting the appropriate option from GWLF menus. The weather file is arranged by months (April - March) 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. The remaining listings are text files of the various program outputs.

TRANSPRT.DAT

```
7,3
.1,0,0,2.7,0,.065
.03
.13
1.63
0
0
"APR",.51,13.1,0,.34
"MAY",.845,14.3,1,.34
"JUNE",.98,15,1,.34
"JULY",1,14.6,1,.34
"AUG",1.02,13.6,1,.34
"SEPT",1.03,12.3,1,.34
"OCT",1.01,10.9,1,.09
"NOV",.5,9.7,0,.09
"DEC",.44,9,0,.09
"JAN",.49,9.3,0,.09
"FEB",.51,10.4,0,.09
"MAR",.51,11.7,0,.09
"CORN",3430,83.8,.214
"HAY",13085,79.4,.012
"PASTURE",5093,73.1,.016
"INACTIVE",3681,73.1,.017
"FOREST",56682,73.3,0
"LOGGING",20,0,.217
"BARN YARDS",41,92.2,0
"RESIDENTIAL",650,77.8,0
"COMMERCIAL",90,89.3,0
"INDUSTRIAL",101,85.5,0
```

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
.008,.002
.237,.015
.234,.011
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
```

WEATHER.DAT

```
30
11,.03
5,.05
6,.23
1,0
4,.66
-1,.08
-1,.2
0,.03
1,1.68
3,1.8
3,0
7,0
6,0
6,.58
4,.13
4,.18
6,.36
4,.03
3,0
5,0
8,0
14,0
13,0
13,0
14,0
16,0
14,2.24
13,2.36
9,.05
9,0
31
8,.15
8,0
9,0
10,1.83
  .
  .
  .
```

TRANSPRT.TXT

```
TRANSPRT DATA

LAND USE        AREA(ha)        CURVE NO      KLSCP
CORN             3430            83.8          .214
HAY              13085           79.4          .012
PASTURE          5093            73.1          .016
INACTIVE         3681            73.1          .017
FOREST           56682           73.3          0
LOGGING          20              0             .217
BARN YARDS       41              92.2          0
RESIDENTIAL      650             77.8          0
COMMERCIAL       90              89.3          0
INDUSTRIAL       101             85.5          0

MONTH    ET CV()    DAY HRS   GROW. SEASON   EROS. COEF
APR       .51        13.1      0              .34
MAY       .8499999   14.3      1              .34
JUNE      .9799999   15        1              .34
JULY      1          14.6      1              .34
AUG       1.02       13.6      1              .34
SEPT      1.03       12.3      1              .34
OCT       1.01       10.9      1              8.999999E-02
NOV       .5         9.7       0              8.999999E-02
DEC       .44        9         0              8.999999E-02
JAN       .49        9.3       0              8.999999E-02
FEB       .51        10.4      0              8.999999E-02
MAR       .51        11.7      0              8.999999E-02

ANTECEDENT RAIN+MELT FOR DAY -1 TO DAY -5
 .03      .13       1.63      0        0

INITIAL UNSATURATED STORAGE(cm)-  0
INITIAL SATURATED STORAGE(cm)  -  2.7
RECESSION COEFFICIENT          -  .1
SEEPAGE COEFFICIENT            -  0
INITIAL SNOW(cm water)         -  0
SEDIMENT DELIVERY RATIO        -  6.500001E-02
```

NUTRIENT.TXT

```
NUTRIENT DATA

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

LAND USE            NITR.BUILD-UP(kg/ha-day)     PHOS.BUILD-UP(kg/ha-day)
RESIDENTIAL               .008                         .002
COMMERCIAL                .237                         .015
INDUSTRIAL                .234                         .011

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):       .34
PHOSPHORUS IN GROUNDWATER(mg/l):     .013
NITROGEN IN SEDIMENT(mg/kg):         3000
PHOSPHORUS IN SEDIMENT(mg/kg):       1300

MANURE SPREADING JAN THRU MAR
```

SUMMARY.TXT

```
example 1     3 -year means


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

APR      10.7             2.1          6.7          0.5          7.2
MAY      10.3             6.4          6.3          0.5          6.8
JUNE      7.2             9.5          2.0          0.0          2.0
JULY      7.7            11.6          0.1          0.0          0.1
AUG       7.8            10.0          0.0          0.0          0.0
SEPT     12.7             6.1          0.0          0.1          0.1
OCT      11.3             3.1          2.4          0.2          2.7
NOV       8.9             0.7          6.9          0.7          7.7
DEC       5.8             0.2          5.0          0.8          5.7
JAN       3.6             0.1          3.3          0.3          3.6
FEB       9.2             0.2          5.1          3.1          8.2
MAR       8.6             0.8          7.2          1.5          8.7
------------------------------------------------------------------
ANNUAL 103.7             51.0         45.1          7.7         52.8

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

APR       47.9       0.1       28.1       30.2       1.9       2.2
MAY       57.4       0.5       27.5       30.3       1.9       2.7
JUNE      28.4       0.0        9.7       10.3       1.1       1.1
JULY      32.2       0.0        4.1        4.6       0.8       0.9
AUG       32.1       0.0        4.1        4.8       0.9       0.9
SEPT      64.4       0.1        5.6        8.6       1.0       1.3
OCT       16.9       0.2       13.7       17.0       1.3       1.8
NOV       11.7       1.7       31.3       38.2       2.1       4.5
DEC        0.7       1.8       25.3       32.6       1.9       4.4
JAN        0.8       0.4       18.0       19.9       1.7       2.3
FEB        1.0       8.1       59.8       86.1       5.7      16.4
MAR        5.5       6.5       48.6       69.7       4.3      12.9
-------------------------------------------------------------------
ANNUAL   299.2      19.4      275.8      352.2      24.6      51.2
```

```
SOURCE          AREA    RUNOFF   EROSION  DIS.NITR TOT.NITR DIS.PHOS TOT.PHOS
                (ha)     (cm) (tonne/ha)    -----------(tonnes)---------

CORN            3430     14.61    61.60    39.37    80.58     5.68    23.54
HAY             13085    10.53     3.45    38.59    47.40     2.07     5.89
PASTURE         5093      6.68     4.61    10.21    14.78     0.85     2.83
INACTIVE        3681      6.68     4.89     3.94     7.45     0.32     1.84
FOREST          56682     6.78     0.00     7.30     7.30     0.23     0.23
LOGGING         20        0.00    62.46     0.00     0.24     0.00     0.11
BARN YARDS      41       30.89     0.00     3.71     3.71     0.65     0.65
RESIDENTIAL     650       9.38     0.00     0.00     1.87     0.00     0.47
COMMERCIAL      90       23.20     0.00     0.00     7.69     0.00     0.49
INDUSTRIAL      101      16.71     0.00     0.00     8.51     0.00     0.40
GROUNDWATER                                127.04   127.04     4.86     4.86
POINT SOURCE                                45.60    45.60     9.90     9.90
-------------------------------------------------------------------------------
TOTAL                                      275.75   352.17    24.56    51.19
```

ANNUAL.TXT

```
example 1   YEAR SIMULATION

YEAR    PRECIP        EVAPOTRANS    GR.WAT.FLOW   RUNOFF       STREAMFLOW
          -----------------(cm)---------------------------------
 1      106.8           51.6          48.4          6.0          54.4
 2      100.1           51.3          40.9         10.3          51.3
 3      104.3           50.0          45.9          6.9          52.8

YEAR    EROSION    SEDIMENT   DIS.NITR   TOT.NITR   DIS.PHOS   TOT.PHOS
         --(1000 tonnes)--         ----------(tonnes)---------------
 1       341.8       22.2      263.2      347.7       22.6       52.8
 2       301.7       19.6      291.4      367.0       26.6       53.4
 3       254.1       16.5      272.6      341.8       24.5       47.4
```

MONTHLY.TXT

```
example 1   YEAR  1

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

APR       10.7              1.9          7.3          0.9          8.3
MAY       14.9              6.5          6.8          0.9          7.7
JUNE       3.9              9.5          4.0          0.0          4.0
JULY       7.1             11.9          0.2          0.0          0.2
AUG        8.8              9.9          0.0          0.0          0.0
SEPT      14.1              6.1          0.0          0.2          0.2
OCT       11.0              3.4          3.0          0.1          3.0
NOV       13.0              1.0          7.9          1.1          8.9
DEC        3.8              0.3          5.6          0.0          5.6
JAN        3.0              0.2          3.5          0.0          3.5
FEB        2.6              0.1          1.6          0.2          1.7
MAR       14.1              0.8          8.7          2.7         11.3
-----------------------------------------------------------------
YEAR     106.8             51.6         48.4          6.0         54.4

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

APR         46.1       0.3      34.6      36.6       2.3       2.8
MAY         89.2       1.0      33.4      38.1       2.3       3.8
JUNE        14.3       0.0      15.0      15.0       1.3       1.3
JULY        20.5       0.0       4.3       4.3       0.8       0.8
AUG         25.2       0.0       3.8       3.9       0.8       0.8
SEPT        86.5       0.2       6.2      11.1       1.0       1.6
OCT         12.1       0.0      13.3      14.6       1.2       1.4
NOV         31.0       4.4      37.9      54.6       2.5       8.6
DEC          1.1       0.0      20.0      20.5       1.5       1.5
JAN          2.5       0.0      13.7      13.7       1.2       1.2
FEB          0.0       0.3      12.0      15.7       1.4       2.0
MAR         13.4      16.0      69.0     119.6       6.1      27.1
------------------------------------------------------------------
YEAR       341.8      22.2     263.2     347.7      22.6      52.8
```

```
SOURCE          AREA    RUNOFF    EROSION  DIS.NITR TOT.NITR DIS.PHOS TOT.PHOS
                (ha)     (cm)      (t/ha)    ------------(tonnes)----------

CORN            3430     13.06     70.37     29.30    76.36     4.04    24.44
HAY             13085     8.84      3.95     32.40    42.46     1.74     6.10
PASTURE         5093      4.93      5.26      7.53    12.76     0.63     2.89
INACTIVE        3681      4.93      5.59      2.90     6.92     0.24     1.97
FOREST          56682     5.03      0.00      5.42     5.42     0.17     0.17
LOGGING         20        0.00     71.35      0.00     0.28     0.00     0.12
BARN YARDS      41       30.20      0.00      3.63     3.63     0.63     0.63
RESIDENTIAL     650       7.66      0.00      0.00     1.85     0.00     0.46
COMMERCIAL      90       21.99      0.00      0.00     7.62     0.00     0.48
INDUSTRIAL      101      15.24      0.00      0.00     8.43     0.00     0.40
GROUNDWATER                                 136.42   136.42     5.22     5.22
POINT SOURCE                                 45.60    45.60     9.90     9.90
-------------------------------------------------------------------------------
TOTAL                                       263.19   347.74    22.56    52.78

example 1   YEAR   2

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

APR     11.7          2.1          8.6          0.3          8.8
MAY      3.0          6.5          4.1          0.0          4.1
JUNE    10.4          8.9          0.2          0.0          0.2
JULY     9.2         11.5          0.0          0.0          0.0
AUG      9.4         10.6          0.0          0.0          0.0
SEPT    10.6          6.5          0.0          0.2          0.2
OCT     10.0          3.0          2.0          0.4          2.4
NOV      8.1          0.5          6.0          1.2          7.2
DEC      5.9          0.1          5.5          0.9          6.4
JAN      2.1          0.0          2.2          0.1          2.4
FEB     16.5          0.5          8.3          7.3         15.5
MAR      3.1          0.9          4.0          0.0          4.0
-----------------------------------------------------------------
YEAR   100.1         51.3         40.9         10.3         51.3
```

	EROSION	SEDIMENT	DIS.NITR	TOT.NITR	DIS.PHOS	TOT.PHOS
	--(1000 tonnes)--		----------(tonnes)----------			
APR	60.7	0.0	32.0	33.6	2.1	2.2
MAY	8.4	0.0	15.4	15.4	1.3	1.3
JUNE	50.9	0.0	4.7	6.4	0.9	1.0
JULY	49.6	0.0	4.0	4.9	0.9	0.9
AUG	54.6	0.0	4.5	6.5	0.9	1.0
SEPT	49.3	0.0	6.4	8.2	1.0	1.2
OCT	23.2	0.2	14.4	17.8	1.4	1.9
NOV	0.7	0.7	32.8	36.7	2.3	3.3
DEC	0.2	0.5	28.1	31.0	2.0	2.8
JAN	0.0	0.0	13.5	14.8	1.5	1.6
FEB	3.0	18.1	120.0	175.8	11.1	34.8
MAR	0.9	0.1	15.5	15.9	1.3	1.4
YEAR	301.7	19.6	291.4	367.0	26.6	53.4

SOURCE	AREA (ha)	RUNOFF (cm)	EROSION (t/ha)	DIS.NITR	TOT.NITR	DIS.PHOS	TOT.PHOS
				------------(tonnes)----------			
CORN	3430	17.31	62.11	48.70	90.24	7.09	25.10
HAY	13085	13.14	3.48	48.15	57.03	2.58	6.43
PASTURE	5093	9.23	4.64	14.10	18.72	1.18	3.17
INACTIVE	3681	9.23	4.93	5.44	8.98	0.44	1.98
FOREST	56682	9.33	0.00	10.05	10.05	0.32	0.32
LOGGING	20	0.00	62.98	0.00	0.25	0.00	0.11
BARN YARDS	41	33.43	0.00	4.02	4.02	0.70	0.70
RESIDENTIAL	650	11.96	0.00	0.00	1.70	0.00	0.43
COMMERCIAL	90	25.96	0.00	0.00	7.18	0.00	0.45
INDUSTRIAL	101	19.46	0.00	0.00	7.86	0.00	0.37
GROUNDWATER				115.38	115.38	4.41	4.41
POINT SOURCE				45.60	45.60	9.90	9.90
TOTAL				291.42	366.99	26.62	53.36

```
example 1   YEAR  3

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

APR      9.7          2.2           4.3          0.1          4.4
MAY     12.9          6.4           8.0          0.7          8.7
JUNE     7.4         10.2           2.0          0.0          2.0
JULY     6.9         11.4           0.1          0.0          0.1
AUG      5.1          9.4           0.0          0.0          0.0
SEPT    13.3          5.8           0.0          0.0          0.0
OCT     13.0          2.9           2.2          0.3          2.5
NOV      5.6          0.7           6.9          0.0          6.9
DEC      7.7          0.1           3.8          1.4          5.2
JAN      5.7          0.1           4.3          0.6          4.9
FEB      8.4          0.1           5.4          1.9          7.3
MAR      8.6          0.8           8.9          1.9         10.8
---------------------------------------------------------------
YEAR   104.3         50.0          45.9          6.9         52.8

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

APR      36.9       0.0      17.9      20.4       1.4       1.6
MAY      74.5       0.6      33.6      37.3       2.2       3.1
JUNE     20.1       0.0       9.5       9.5       1.0       1.0
JULY     26.7       0.0       4.1       4.6       0.8       0.9
AUG      16.6       0.0       3.8       4.0       0.8       0.8
SEPT     57.4       0.0       4.1       6.4       0.9       1.0
OCT      15.6       0.3      13.3      18.4       1.3       2.0
NOV       3.5       0.0      23.2      23.3       1.6       1.6
DEC       0.8       4.9      27.8      46.3       2.1       8.9
JAN       0.0       1.1      26.7      31.1       2.5       4.0
FEB       0.0       6.0      47.3      66.8       4.4      12.3
MAR       2.0       3.6      61.3      73.6       5.3      10.1
----------------------------------------------------------------
YEAR    254.1      16.5     272.6     341.8      24.5      47.4
```

SOURCE	AREA	RUNOFF	EROSION	DIS.NITR	TOT.NITR	DIS.PHOS	TOT.PHOS
	(ha)	(cm)	(t/ha)	(tonnes)			
CORN	3430	13.46	52.32	40.13	75.13	5.92	21.08
HAY	13085	9.61	2.93	35.22	42.70	1.89	5.13
PASTURE	5093	5.88	3.91	8.99	12.87	0.75	2.43
INACTIVE	3681	5.88	4.16	3.46	6.45	0.28	1.57
FOREST	56682	5.98	0.00	6.44	6.44	0.20	0.20
LOGGING	20	0.00	53.05	0.00	0.21	0.00	0.09
BARN YARDS	41	29.04	0.00	3.49	3.49	0.61	0.61
RESIDENTIAL	650	8.51	0.00	0.00	2.06	0.00	0.51
COMMERCIAL	90	21.65	0.00	0.00	8.26	0.00	0.52
INDUSTRIAL	101	15.45	0.00	0.00	9.26	0.00	0.44
GROUNDWATER				129.32	129.32	4.94	4.94
POINT SOURCE				45.60	45.60	9.90	9.90
TOTAL				272.65	341.78	24.49	47.44

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