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LITERATURE REVIEW: COMPUTER AIDED ASSESSMENT TECHNIQUES FOR NONPOINT SOURCE DISCHARGES

ABSTRACT Computer models and Geographic Information Systems (GISs) are valuable tools for assessing nonpoint source discharges. Because of the diffused nature and variable flow associated with storm water run-off, it is difficult to design an inexpensive sampling program to assess the impact of nonpoint source pollution. Computer modeling and GISs can help process limited data and make assessments of nonpoint source discharges from both surface water and groundwater sources. Modeling approaches range from simple loading function calculations to the use of sophisticated hydrological and water quality-oriented computer software. GISs have great potential for reducing the cost of assessing nonpoint source pollution.

NAVAL CIVIL ENGINEERING LABORATORY PORT HUENEME CALIFORNIA 93043-5003

METRIC CONVERSION FACTORS

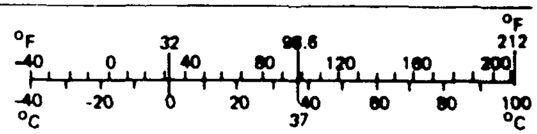
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit *temperature*	5/9 (after *subtracting* 32)	Celsius *temperature*	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10 286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	*Celsius* temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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Computer models and Geographic Information Systems (GISs) are valuable tools for assessing nonpoint source discharges. Because of the diffused nature and variable flow associated with storm water run-off, it is difficult to design an inexpensive sampling program to assess the impact of nonpoint source pollution. Computer modeling and GISs can help process limited data and make assessments of nonpoint source discharges from both surface water and groundwater sources. Modeling approaches range from simple loading function calculations to the use of sophisticated hydrological and water quality-oriented computer software. GISs have great potential for reducing the cost of assessing nonpoint source pollution.

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EXECUTIVE SUMMARY

This report responds to one of the recommendations contained in the Initiation Decision Report, TN-1798, for the Navy's nonpoint source pollution program: that computer models be developed and utilized to reduce sampling requirements and simplify the identifying and prioritizing of Navy NPS.

Recent amendments to the Clean Water Act require the Navy to be responsive to State's authority in the control of nonpoint sources (NPS) of water pollution. Under the Act, many States will be requiring the Navy to implement measures to reduce their nonpoint source pollution. As nonpoint sources of pollution are diffuse and intermittent, it is difficult to design a simple and inexpensive sampling and analysis program to determine if a nonpoint source discharge from a Navy installation can cause a significant impact on a receiving water. Without an inexpensive method to assess nonpoint source pollution, it will be difficult to prioritize our needs and design cost effective control measures.

Many loading functions, a simple series of formulas, are identified to perform a quick and inexpensive rough estimate of NPS pollution loadings from agricultural out-leases, housing areas, office areas, and commercial areas. No loading functions are available for estimating NPS from industrial areas, impact areas, rifle ranges, demolition areas, and similar areas.

Eighteen different computer models were identified to provide a more accurate assessment NPS from agricultural areas and urban areas. The selection and use of a model depends on several factors, including desired level of accuracy, type and source of pollutant, data requirements, and cost. The Navy should consider using these models where more accurate determination of pollutant loads is needed for an agricultural out-lease or nonindustrial base area, such as housing areas and commercial/office areas. As in the case of loading functions, computer models do not exist for industrial and other areas.

Geographic information systems (GISs) provide the ideal platform for running NPS computer models. They can reduce data entry requirements by using inexpensive, readily available digitized geographic data. Also, GIS enables the user to perform "what-if" analyses regarding the effects of changing a criterion on the amount of nonpoint source pollution from a site or area. For example, one can change the land use, slope, vegetation cover, etc., and immediately see the effect of these changes on the type and amount of pollutants discharged.

In most cases, existing computer models and loading functions can be used to reduce sampling and to prioritize our civilian-type NPS. It is recommended that the Navy begin by using these techniques to assess NPS at our residential, commercial, and out-leased agricultural areas.

These techniques can also be used for assessing NPS from light industrial areas where the land surface is not disturbed as part of the operation and chemicals are not released to the environment.

Computer models and loading functions do not exist for military unique areas, industrial areas, and areas where the soil is routinely disturbed or chemicals are discharged to the environment. These areas include impact zones, ordnance demolition areas, training areas, rifle ranges, shipyards, and aviation depots. For these areas we recommend developing loading functions and computer models for sources not already addressed by the EPA or academia. Use of loading functions and computer models will reduce the cost of assessing Navy NPS pollution, aid in prioritizing the Navy's environmental problems, and ensure cost effective use of constrained resources.

CONTENTS

CHAPTER 1

INTRODUCTION

The Navy's Initiation Decision Report for Nonpoint Source (NPS) Discharge (June 1990) recommends the identification and development of predictive models to reduce sampling requirements and simplify the identifying and prioritizing of Navy NPS pollution. This report is the first step in the process of identifying models.

The Water Quality Act of 1987 amended the Federal Clean Water Act to require the States to develop detailed plans for controlling nonpoint sources of water pollution. Such nonpoint source programs are currently being developed by the States in accordance with the terms and conditions set forth in Section 319 of the Act. Many State programs emphasize implementation on both a regulatory and voluntary basis and support public awareness and participation.

A nonpoint source discharge is defined as a discharge that does not originate from a single point or operation, but from a larger area. The EPA states that, for the purpose of implementation, NPS pollution is defined as follows (EPA, July 1987):

> NPS pollution is caused by diffuse sources that are not regulated as point sources and normally is associated with agricultural, silvicultural, and urban runoff, runoff from construction activities, etc. Such pollution results in the human-made or human-induced alteration of the chemical, physical, biological, and radiological integrity of water. In practical terms, nonpoint source does not result from a discharge at a specific, single location (such as a pipe) but generally results from land runoff, precipitation, atmospheric deposition, or percolation. Pollution from nonpoint sources occurs when the rate at which pollutant materials entering water bodies or groundwater exceeds natural levels.

A nonpoint source can be collected, such as in a storm water sewer system, and be conveyed to a point discharge, subject to regulation.

The impact of nonpoint source pollution on surface water quality differs from that of point sources. Novotny and Chesters (1981) summarized the differences as follows:

Point Source	Nonpoint Source
• Fairly steady flow and quality	• Highly dynamic in random intermittent intervals
• Variability ranges less than than one order of magnitude	• Variability ranges often more than several orders of magnitude
• The most severe impact is during low flow periods	• The most severe impact is during or following a storm event
• Enters receiving water at identifiable points	• Point of entry often cannot be identified or defined
• Primary parameters of interest: BOD, DO, nutrients, suspended solids	• Primary parameters of interest: sediment, nutrients, toxic nutrients, suspended solids, pH, DO

A typical flow diagram of nonpoint source pollution is presented in Figure 1-1 illustrating the flow and pollutant load variability.

Two types of models are available to assess NPS pollution. The first type of model includes simple loading functions. A loading function, also known as a loading model, is a mathematical expression which can be used to calculate the emission of a pollutant. These are used to quickly estimate the quantity of pollutants in a discharge and simulation models to more accurately determine pollutant discharges. The second type of model is the geographic information system (GIS), which uses remotely sensed data to identify sources, determine surface and subsurface transport routes, and determine impacts of NPS pollution.

The methodology used to review NPS computer models consisted of three phases:

1. **Model Identification**: Model identification was based on a review of abstracts obtained from computer searches and available documentation at the Environmental and Ground Water Institute (EGWI) and the University of Oklahoma Libraries. This phase focused on the identification of available models and their area of application and relevance to Navy NPS problems.

2. **Model Acquisition**: Model acquisition was initiated by telephone contacts with various agencies, mainly: (1) U.S. EPA laboratories and modeling centers; (2) USDA Agricultural Research Service; and (3) USDA Soil Conservation Service laboratories. Contacts with individual model users were also helpful. The results of this phase consisted of the acquisition of a set of mathematical models for NPS evaluation of agriculture, urban, and related areas.

3. **Model Documentation**: Model documentation consisted of reviewing the theory and applicability of relevant models. The documentation was obtained temporarily through interlibrary loans, with the help of the University of Oklahoma Library. Summary information on computer models is contained in Chapter 2 and Appendix A.

The applicability and feasibility of using a geographic information system (GIS) and remotely sensed data as a tool to perform certain tasks was assessed. The three tasks are (1) locating and identifying sources of NPS pollution, (2) determining surface and subsurface transport routes of NPS pollutants and, (3) identifying impact sites of pollutants.

An extensive literature search was undertaken, which identified numerous applications of GIS and remote sensing in similar projects. However, this is a relatively young field, and no general methodologies have been derived. Therefore, the scope of this information, which is provided in Chapter 3, in general terms, is to identify how different authorities have approached the application, and how a protocol could be established. The references listed in this report represent only the most obviously pertinent examples of GIS and remote sensing applications; many other papers that address the issue tangentially, or in part, have not been referenced here, but would be used for developing a full protocol.

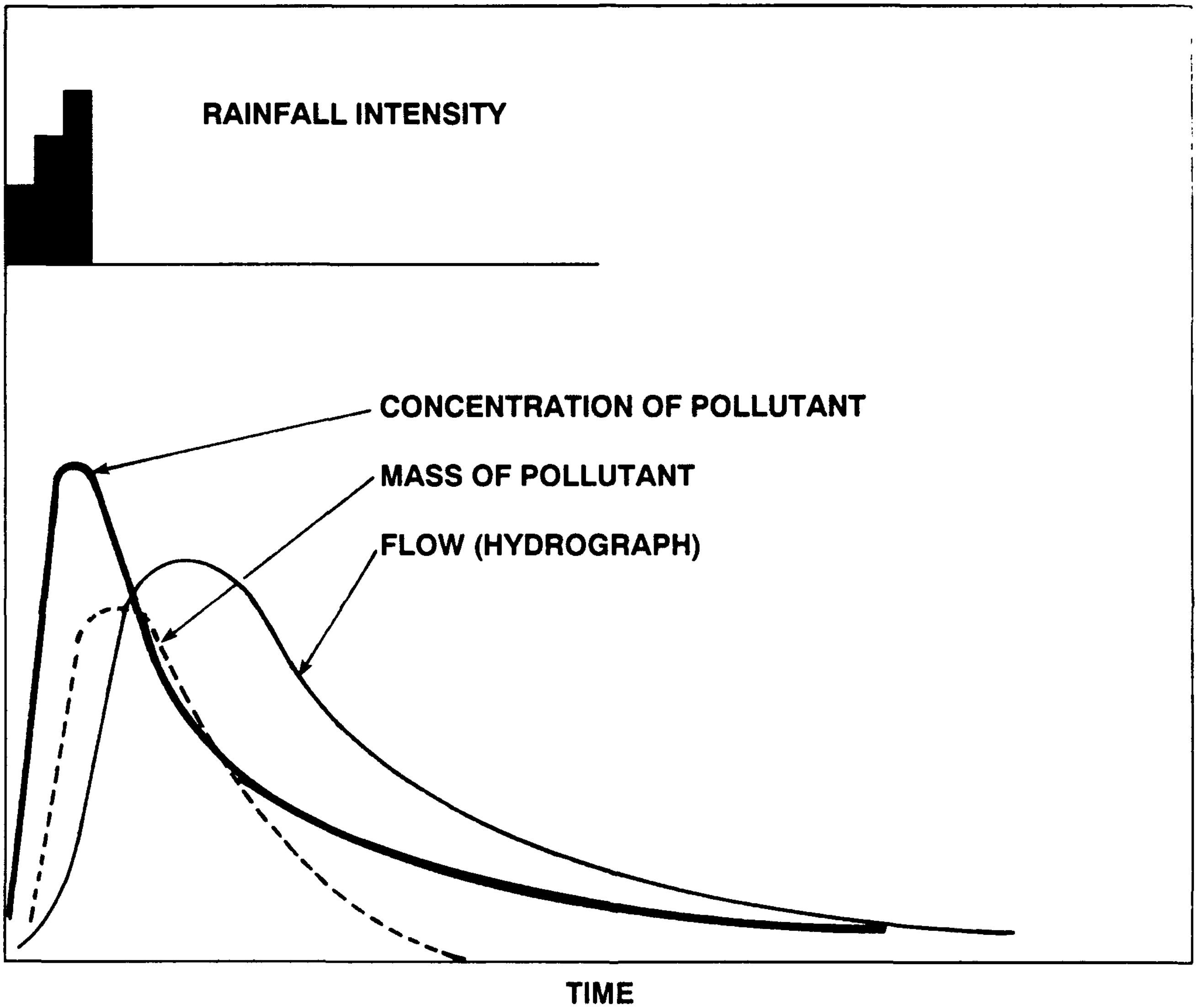

Figure 1. 1: Flow and quantity histogram from nonpoint sources.

CHAPTER 2

COMPUTER MODELING FOR NPS ASSESSMENT

A nonpoint source pollutant is a substance generated by man-induced activities that has the potential for adversely affecting the environment. A nonpoint pollution source is a land area which can be treated as a unit with respect to land use practices and potential for pollutant discharges. Nonpoint pollutant sources that have received the most attention in nonpoint pollution studies are:

- Agriculture and related areas
- Urban and related areas
- Construction areas
- Mining areas
- Precipitation and atmospheric deposition

Pollutants discharged from nonpoint sources comprise a mixture of substances. The major pollutants are nutrients, sediment, pesticides and herbicides, metals and acidity from mine drainage, salinity and total dissolved solids, radioactivity, heavy metals, and pathogens. Categories of Navy NPS and major pollutants from those sources are discussed in the NPS IDR, TN-1798.

NONPOINT POLLUTION CHARACTERISTICS

Processes that create nonpoint source pollution are very complex systems that are difficult to describe mathematically; and since it is a surface phenomenon, it is very expensive to monitor adequately. This type of system depends on a large number of naturally and randomly occurring factors and man-induced factors. Some characteristics of NPS pollution are that it is discontinuous, highly variable, nonuniform, not easy to monitor, and transported through multiple routes.

Surface nonpoint source discharges represent a discontinuous and highly variable process. They occur during rainfall events when storm runoff from the land surface carries sediment, sediment-adsorbed chemicals, and dissolved chemicals into receiving waters. Dissolved chemicals may percolate through the soil, reach the groundwater table, and eventually reappear in the surface water as base flow.

Nonpoint source pollution arises nonuniformly, transits overland according to various mechanisms, and therefore cannot be easily monitored at its point of origin. Nonpoint source pollution is a dynamic and stochastic phenomenon with multimedia dimensions. It is dynamic in the sense that land uses and configurations change over time, thus making the pollutant load vary spatially and temporally. It is stochastic because most of the governing processes are induced by hydrological factors. In fact, the hydrological cycle plays the major role in the transport of pollutants from their original source to the receiving environment. It is multimedia in dimension since it involves continuous land-water-atmosphere interactions.

Transport routes of pollutants from nonpoint sources include surface runoff, interflow to surface water, percolation to ground water, direct losses to the atmosphere, plant uptake, and soil attenuation and transformations.

The scale at which the nonpoint pollution system can be addressed is of major importance. It could consist of a watershed/river basin, a homogeneous field with respect to a specific land use, or a regional area with various land uses. A watershed system has defined physical boundaries and its response to pollutants is determined by the combination of physical characteristics of soils, topography, geology, vegetation, and drainage networks.

Inputs to the system can be characterized as either (1) deterministic and controllable, consisting of land usage techniques, management practices, nutrient applications, etc.; or (2) stochastic, natural, and uncontrolled, consisting mainly of climatological factors. Because of the latter group, the outputs lean toward a stochastic type and therefore are difficult to predict accurately with simple empirical formulations.

The inputs and outputs of a watershed system can be grouped under five categories: natural input, management input, airshed output, surface water flow output, and subsurface water flow output. These inputs and outputs are shown in Figure 2-1. Natural inputs include precipitation; temperature; radiation; wind; relative humidity; and pollutant rain-out of nutrients, pesticides, particulates, and heavy metals. Management inputs include land use, pesticides application, cultural and management practices, and nutrient addition. Airshed outputs include chemical spray drift, dust-adsorbed chemicals, and evapotranspired water. Surface waterflow outputs include surface runoff, dissolved chemicals in surface runoff, sediment and sediment-adsorbed chemicals, and detritus. Subsurface water flow outputs are dissolved chemicals in saturated and unsaturated zones.

ESTIMATION OF NONPOINT SOURCE POLLUTION

Nonpoint source pollution load estimates have been of major concern since this type of pollution was identified as an environmental problem. Water quality legislation over the last 20 years has stimulated the development of environmental system models capable of simulating various processes, functioning as a basis for system design of control practices and, at the same time, aiding in decision making processes for better management and planning of both aquatic and land resources.

Table 2-1 identifies for each source area the main pollutants for which load estimation methods have been developed (loading functions or simulation models). It is important to mention that for some nonpoint sources, quantitative estimation tools have not been developed because some source/land uses are very irregular in occurrence, data on loads are not available, and some sources cannot be described in terms of pollution load. In such cases it may be necessary to develop qualitative methods to describe the magnitude of these sources.

Loading Functions for Agriculture and Related Areas

Loading functions are simple mathematical expressions that have been developed to evaluate the production or the transport of a pollutant from a specific area under a specific usage. The agricultural and related areas category of land use includes Navy outleased crop land, pasture and range land, silviculture land, forests, irrigated areas and feed lots. Surface water pollutants from these areas include sediment, organic matter, nutrients, and pesticides. Groundwater concerns focus mainly on nitrogen (NO_3) leaching, and pesticide contamination. The impact of such pollutants is primarily a chronic and cumulative problem; however, acute contamination can be observed at high concentrations.

Two types of loading functions have been developed for Navy outleased agricultural areas. One type addresses sediment production and transport and the other addresses chemical production and transport.

1. Agricultural Sediment Yield Estimation

The three main sediment yield estimation methods include the Universal Soil Loss Equation, the Sediment Generation Model (Negev's Model), and the Delivery Ratio Method. Table 2-2 presents a brief description of the mathematical expressions used in each of the three methods for determining sediment yields.

a. Universal Soil Loss Equation

The Universal Soil Loss Equation method is the most common estimator of sheet and rill erosion. Five factors are considered the most significant in sediment production from topsoil.

Rainfall characteristics define the ability of the rain to splash and erode soil. Rainfall energy is determined by drop size, velocity, and intensity characteristics of rainfall.

Soil properties affect both detachment and transport processes. Detachment is related to soil stability: the size, shape, composition, and strength of soil aggregates and clods. Transport is influenced by permeability of soil to water, which determines infiltration capabilities and drainage characteristics; by porosity, which affects storage and movement of water; and by soil surface roughness, which creates a potential for temporary detention of water.

Slope factors define the transport portion of the erosion process. Slope gradient and slope length influence the flow and velocity of runoff.

Land cover conditions affect detachment and transportation of soil. Land cover by plants and their residues provides protection from the impact of raindrops. Vegetation protects the ground from excessive evaporation, keeps the soil moist, and thus makes the soil aggregates less susceptible to detachment. Residues and stems of plants furnish resistance to overland flow, slowing down runoff velocity and reducing erosion.

Conservation practices concern modification of the soil factor or the slope factor, or both. Practices for erosion control are designed to do one or more of the following: (1) dissipate raindrop impact forces; (2) reduce quantity of runoff; (3) reduce runoff velocity; and (4) manipulate soils to enhance the resistance to erosion.

b. Sediment Generation Model (Negev's Model)

The Sediment Generation Model (Negev's Model) based on short time step calculations is a candidate for use in numerical simulation models. First, it calculates the fine particles produced during each time step within a storm runoff event. The quantity of sediment produced is considered available for immediate transport by overland flow if overland flow occurs during the corresponding time step. If the overland flow does not occur, the sediment produced will accumulate at the surface which acts as a reservoir of available particles. Unlike the Universal Soil Loss Equation (USLE), this method is not substantiated by extensive experimental field data and measurements. Its use requires a knowledge of several empirical factors and coefficients.

c. Delivery Ratio Method

The Delivery Ratio Method (sediment delivery ratio) represents a fraction of the total erosion which is delivered to a stream. In general practice, the sediment delivery ratio is determined for a geographical area or a large river basin in which the magnitude of sediment yield is known at various points (for example, reservoir sedimentation data or sediment load records from stream gaging stations). These sediment yields are correlated to measurable watershed influencing factors. Watershed surface area is the most common factor used, and it gives a nonlinear formulation such as that presented in Table 2-2. The Delivery Ratio Method is widely used in evaluating long-term average annual yield and in predicting reservoir siltation rates.

2. Agricultural Chemical Pollutants

Chemical load estimates from agriculture and related areas can be obtained directly by using corresponding loading functions and potency factors. The principle of these functions is based on the assumption that there is a linear correlation between the sediment yield and each pollutant load: BOD/organic matter, nitrogen, phosphorus or pesticides. The correlation parameter is called the potency factor, which combines the effect of many processes, making it very difficult to estimate accurately. As an empirical approximation, the potency factor can be envisioned as the product of three independent factors: (1) the concentration of pollutant in the surface layer of the soil, (2) the enrichment ratio of pollutant, and (3) the ratio of the mean particle density of surface soil to the mean particle density of eroded sediment. Table 2-3 presents the basic formulation of agricultural chemical loading functions and the corresponding potency factors.

The potency factor concept was developed from observations of substances strongly sorbed to sediment, such as phosphorus. It was also observed that higher concentrations of substances generally existed in eroded sediment rather than in the source soil. This observation led to the development of the enrichment ratio concept.

The effects of other variables, such as watershed slope, rainfall intensity, etc., on the enrichment ratio have been investigated. Hydrologic factors such as runoff and rainfall energy have a greater effect on the enrichment ratio than do soil physical properties.

The use of the loading function concept necessitates the knowledge of the sediment load which can be either determined by empirical expressions such as those presented earlier, or obtained from direct measurements. The corresponding potency factor can also be obtained by direct measurement, extrapolation from published literature, or simulated using chemical application data. Figure 2-2 presents various levels of accuracy that can be selected in simulating a potency factor. Basic data for both sediment losses and chemical applications can be obtained from local Soil Conservation Service offices.

Loading functions have been widely used for estimating expected annual fertilizer loads for BOD, nitrogen, and phosphorus. Because of the need to predict peak concentrations rather than annual loads, loading functions have not been widely used for pesticide pollution prediction. It is also important to mention that while crop lands have been widely studied, more data is needed in other related land uses such as silvicultural areas, where soil disturbance due to harvesting is the main cause of pollutant production.

Loading Functions for Urban and Related Areas

This category of land uses includes residential areas (single family and multi-family), industrial and commercial areas, construction areas, and developing land areas. Navy areas that fit this category include housing areas, commercial areas, construction areas, motor pool areas, and industrial areas similar to civilian industrial areas. The major pollutants of concern are sediment, organic matter, nutrients, pesticides, heavy metals, oil and grease, and pathogens. The main pollutant sources are industries such as steel mills, cement manufacturing and chemical processing; urban runoff containing mud, deposited automotive exhaust and oil and grease, organic debris from tree leaves and grass trimming; and construction area runoff containing sediment and heavy metals.

Solid loading rates and composition from urban and related areas have been widely studied and thoroughly monitored. Average values for various urban zones are well known. The pertinent factors found to influence nonpoint pollution from urban areas are shown in Table 2-4.

a. Solid Load Estimation

The daily total solids load from urban and related areas can be estimated from known daily rates as a function of the street curb length as shown in Table 2-5. For construction areas, various methods of estimation have been developed, but their applicability outside the areas for which they were developed is limited. A statistical relationship can be obtained based on the average slope of the site and the sediment control practices. A simple formulation for estimating the sediment delivery ratio was developed for the U.S. Environmental Protection Agency based on the overland distance between the construction site and the receiving water.

b. Other Pollutants

Loading functions for estimating chemical pollutants from urban areas are based on the estimation of solid loads and can be used for daily estimates. The mathematical expression presented in Table 2-5 is limited to street loadings. The effect of housekeeping practices in the urban area is not reflected in these formulas.

NONPOINT POLLUTION SIMULATION MODELS

Unlike the loading functions, modeling nonpoint source pollution requires an analysis of the complete environmental system. A perturbation in one part of the system or in one contributing factor will affect not only that part, but the whole system, because the parts are linked. The agricultural-environmental system which has received the most attention during the past 20 years, is a combination of hydrologic, ecologic, agronomic, social, and economic subsystems. Because of its multidisciplinary character, nonpoint source pollution control is best addressed as an integrated part of other water quantity and quality programs and land resources development issues.

Nonpoint source pollution modeling poses a multitude of technical, economical, health, and environmental problems. However, with respect to model development, these problems can be grouped into three broad and interrelated categories.

The first category includes chemicals that are washed from a land source in a diffuse form. Certain mining activities and agricultural practices (fertilizer, animal waste, and pesticides application) represent the major components of the category. The main concern in model development is the optimization of the amount and the timing of the chemical application in order to minimize expenses.

The second category consists of those pollutants that constitute primarily an accumulation problem over a long period of time. The pollutants of concern can be naturally occurring, such as sediment, or artificial chemicals at low concentrations with low or chronic toxicity. The accumulation can be physical, such as lake and reservoir siltation, or biological, where the pollutants gradually accumulate in the aquatic food chain. Because of the long-term impact of these types of pollutants, the quantification methods and predictive models are simple, usually empirical, and average annual information is sufficient for developing nonpoint source management plans.

The last category concerns toxic chemicals that constitute mainly environmental and health problems over a short period of time. Predictive models in this category are by far the most difficult to describe mathematically. In addition, they require an extensive program of monitoring and data collection. They usually are expensive to use, difficult to calibrate, and time consuming.

Nonpoint Pollution Simulation Model Selection

Selection of a nonpoint simulation model involves many considerations. Prior to model selection, preliminary studies are required to clearly define the objectives of the project, determine the need to use a model, and define how the expected modeling results can be incorporated in the project. Finally, a set of candidate models need to be identified and used in the selection process. The model selection process can be divided into four phases, each progressively more detailed and requiring more effort. These phases include model applicability tests, cost constraint tests, simplified performance index rating, and advanced performance index rating.

Phase 1: Model Applicability Tests. This phase determines the appropriateness of the models with respect to the objectives of the project. Models are determined to be inappropriate and can either be rejected or put on hold for more detailed considerations and the possibility of modifications. For nonpoint source models, the attributes to be considered in this phase should include:

- model scale (field and basin size)
- process type (continuous, daily, single event)
- land use (agriculture, urban)
- time variable (steady state, dynamic)
- constituents modeled (nitrogen, phosphorus, etc.)
- discretization and limitation (grid size, etc.)
- model components, such as hydrology, erosion, sediment transport, and water quality
- model input requirements such as hydrology and climatology data, land use and soil quality data, field measurement needs, and laboratory experimentation needs

Phase 2: Cost Constraint Tests. This phase considers both the time and cost needed to calibrate, test and apply the models preselected during the previous phase. Cost and time estimation includes model acquisition, equipment required, data acquisition, and manpower costs and qualifications. Factors to be considered in this phase should include:

- computer requirements and costs
- model acquisition costs
- staff requirements and costs
- time requirements including set up and calibration and verification
- data acquisition costs and time for field measurements and laboratory experiments

Phase 3: Performance Index Rating - Simplified. In this phase the selection process is based on the effectiveness of the models preselected in phases 1 and 2. The attributes of each model are compared and appropriately classified using a paired comparison technique.

Phase 4: Performance Index Rating - Advanced. This final phase consists of a more detailed analysis of each model. The selection in this phase requires extensive user insight and experience in water quality analysis and modeling. Model scoring and ranking should be based on attributes such as:

- internal factors and processes included
- model representation accuracy and simplifying assumptions
    - numerical accuracy
    - numerical dispersion
    - stability and sufficiency of available documentation
    - output form and content
    - ability to update
    - ease of modification

The final model selection in phase 4 can be based on a paired comparison of the remaining models, taking into account their expected performance and cost.

Nonpoint Source Model Calibration and Verification

Calibration of mathematical models is of less importance when the model represents well defined physical laws and has a high degree of deterministic formulations. However, calibration and verification in model applications becomes extremely important when empirical descriptions enter into model formulation. Such activities are usually needed to adjust model parameters in order to synchronize the space and time output with the observed measurements and to force simulation results to best describe the real world system.

Nonpoint source models usually include many mathematical equations of an empirical or semi-empirical nature that require a precise knowledge of many coefficients and reaction rates. Typically, only approximate ranges or order of magnitudes are known for the coefficients and reaction rates. A set of measured data is necessary for both calibration and verification of all components of the model separately, starting with the most sensitive components and parameters. For nonpoint source models, it is suggested that calibration of the hydrological unit be made first, followed by the erosion-sediment transport unit, and finally the pollutant components. The process of calibration of nonpoint source models can be time consuming and very costly, especially if the model's input requirements are very high and field measurements are not available and need to be collected.

Once all components of the model, as well as the global model, are calibrated, the verification process can be accomplished by testing the validity of the model using a new set of data, usually the most recent one. Split data sets should be used, one set for calibration and the other for verification. If a satisfactory fit of computed and measured data is reached, the model is ready for the application phase. However, very often the process of calibration and testing needs to be repeated many times until a satisfactory fit is found.

REVIEW OF SELECTED NPS MODELS

The literature was reviewed to identify commonly used nonpoint source models for agricultural areas, urban and related areas, and mixed and complex watersheds. Supporting surface water models were also identified. These models and the parameters modeled are shown in Table 2-6.

The models differ in the pollutants modeled, how the level of pollutants is calculated, the size of the area that can be modeled, the amount of information required, and the level of expertise needed to operate the model. For example, the Water Quality Assessment (WQA) model is an easy to use screening procedure for a wide variety of pollutants. It does not require much data, and the results are not very precise. On the other hand, the Equilibrium Metals Speciation Model (MINTEQ) is a highly specialized model for metals only. It produces highly precise results, but requires a high level of knowledge and experience to properly use it.

The following list of NPS models have been identified and could be used as a starting base for the selection process. A brief description of each model's main features is also presented.

Agriculture and Related Areas

Pesticides Transport and Runoff Model (1-PTR)

Development	Developed for EPA by Crawford and Donigian. The model simulates runoff, erosion/sediment transport, and pesticide losses. It does not account for organic matter and nutrient losses.
Process	Continuous simulations.
Scale	Watershed.
Components	
Hydrology:	Based on Stanford Watershed Model.
Erosion and Sediment Transport:	Based on Negev Model in which the mass of accumulated particles is estimated by a first order accumulation function.
Pesticides Transport:	This subroutine is based on a semi-empirical description of pesticide transport process.
Other Characteristics	The use of this model needs extensive calibration and does not account for nutrients and other substances. However, this model served as a basis for the development of the ARM model which incorporates several subroutines to account for nitrogen and phosphorus losses.

Agricultural Runoff Management Model (2-ARM)

Development	The ARM model was developed by Donigian and Crawford. It simulates runoff (including snow accumulation and melt), sediment transport, pesticides and nutrient loadings to surface water from both surface and subsurface sources.
Process	Continuous simulation/single events.
Scale	Field size area.
Components	
Hydrology:	Uses LANDS submodel to simulate overland inputs into channels based on precipitation and meteorological data and overland characteristics.
Nutrients:	Uses first order reaction rates and includes immobilization, nitrification, plant uptake, and adsorption/desorption processes.

Adsorption/ Desorption: Uses a modified Freundlich adsorption isotherm and accounts for volatilization based on heat transfer principles. The model accounts for biological and chemical decomposition and degradation of pesticides using a first order attenuation function.

Other Characteristics: Applicable to small areas/watersheds.

Agricultural Chemical Transport Model (3-ACTMO)

Development: This model was developed by the USDA Agricultural Research Service. Its main purpose is to simulate the transport of organic chemicals from agricultural land.

Process: Continuous simulation/single events.

Scale: Watershed.

Components

Hydrology: Uses a modified form of the USDAHL-70 model, a Watershed Hydrology model based on "Homogeneous Zones" (soil, land use, etc.).

Erosion/ Sediment: Uses a modified Universal Soil Loss Equation to predict soil loss from a watershed.

Quality/ Chemical: Simulates the movement of chemicals for a single application. The adsorption/desorption process is simulated by linear isotherms. It has an option for simulating nitrogen movement and its various transformations.

Other Characteristics: A small size watershed is recommended as a simulation unit. The model does not require calibration.

Chemicals, Runoff, and Erosion from Agricultural Management Systems Model (4-CREAMS)

Development: This model was developed by the USDA in 1979. It is the first model developed by the Department of Agriculture that accounts for sediment, nutrient, and pesticides.

Process: Continuous formulation.

Scale: Field size areas.

Components

Hydrology:	Based on the Soil Conservation Service Curve Numbers (SCSCN) method. It has also an infiltration based subroutine as a secondary option.
Erosion and Sediment Transport:	Based on overland flow transport capacity, interrill and rill detachment and impoundment deposition.
Quality Subroutines:	Simulate pesticides and nutrient losses, and account for mineralization, nitrification immobilization, leaching, adsorption/desorption, volatilization and degradation.

Other Characteristics — The new version of this model is called "GLEAMS".

Ground Water Loading Effects of Agricultural Management Systems (5-GLEAMS)

Development — The GLEAMS model was developed as an extension of CREAMS to evaluate the impact of management practices on potential pesticide leaching below the root zone as well as surface runoff and sediment losses.

Process — Storm events.

Scale — Field size area.

Component

Hydrology: The hydrology component uses daily climatic data to calculate the water balance in the root zone. Precipitation is partitioned between surface runoff and infiltration into the soil surface. It uses the curve number method of estimating runoff as modified by Williams and Nicks. A seasonally frozen-soil representation was added to better estimate snowmelt runoff. A storage-routing technique is used to simulate redistribution of infiltrated water within the root zone, and percolation out of the bottom of the root zone is estimated. Soil evaporation and plant transpiration are estimated with a modified Penman equation.

Erosion and Sediment Transport: It uses a modified Universal Soil Loss Equation (USLE) for storm-by-storm estimates of rill and interrill erosion in overland flow areas. Channel and pond elements were added to calculate erosion or deposition in the field delivery system for estimating sediment yield at the edge of the field. Eroded soil is routed with runoff by particle size, which enables calculation of storm-by-storm sediment enrichment ratios for use in estimating adsorbed pesticide transport.

Quality: Concepts of the CREAMS pesticide component for surface losses in runoff and with sediment were retained in GLEAMS. The same adsorption characteristics were coupled with the water storage-routing technique to route pesticides within and through the root zone. Upward movement of pesticides in the soil by evaporation, and plant uptake by transpiration were included in the modification.

Other Characteristics: This model has been shown to be effective in assessing potential pesticides leaching below the root zone (Leonard, et al., 1988).

Agricultural Nonpoint Pollution Model (6-AGNPS)

Development: This model was developed at the North Central Soil Conservation Research Laboratory (MN). It works on a cell basis where the watershed is divided into uniform grids for input and analysis (Young, et al., 1989).

Process: Storm event.

Scale: Watershed.

Component

Hydrology: Uses SCS - curve number method to simulate runoff from the watershed. The watershed can be divided into a maximum of 2000 cells.

Erosion: Uses the Universal Soil Loss Equation to estimate erosion at each cell and evaluate sediment yield.

Quality: The chemical transport routine in AGNPS estimates nitrogen, phosphorus, and COD throughout the watershed and considers also point sources such as feed lots. Chemical transport calculations are divided into soluble and sediment-adsorbed yields using loading functions and potency factors (extraction coefficients). The model considers streambank, streambed, and gully erosion as contributing point sources.

Other Characteristics: Because of its grid pattern, this model can be linked to a geographical information system to automate the collection and feed of certain input data.

Urban and Related Areas

Storage, Treatment, and Overflow Model (1-STORM)

Development: Developed for the U.S. Army Corps of Engineers. It is a quasi-dynamic program that simulates overland surface runoff, sediment and sediment adsorbed pollution. The water quality parameters include total nitrogen, BOD, orthophosphate, and total and volatile particulates.

Process: Continuous (new version).

Scale: Urban watersheds (primarily).

Components

Hydrology: Uses a modified rational formula.

Erosion: Uses the Universal Soil Loss Equation.

Quality: Considers pollutant losses from pervious and impervious areas to which simple first order concepts are applied to account for pollutant removal.

Other Characteristics: Requires a large amount of input data. Runoff computation using the rational formula is subject to large errors.

Stormwater Management Model (2-SWMM)

Development: This model was developed for the U.S. EPA to simulate overland water quantity and quality produced by storms in urban watersheds. The fourth version of this model will be released in the near future.

Process	Continuous (new version 3 and 4)/single events.
Scale	Urban watershed.
Components	
Hydrology:	It uses a distributed parameters submodel (RUNOFF) which simulates runoff based on the concept of surface storage balance and the use of small homogenous subcatchments (up to 200). A transport routine (TRANSPORT) uses storm water runoff generated by RUNOFF and distributed among the various routes and accounts for infiltration (INFIL) and the effect of natural and/or man-made storages and dampening of storm runoff peaks.
Sediment/ Pollution Load:	For impervious areas, the daily/hourly increase in particle accumulation are computed based on a linear formulation. For pervious areas, sediment load is determined based on the USLE (a modified form). Pollutants other than sediment are computed using the concept of Potency Factors.
Other Characteristics	The application of this model is limited to drainage areas ranging from 5 to 2000 ha.

Mixed and Complex Watersheds

Overland Flow and Pollution Generation Model (1-LANDRUN)

Development	The development of this model was sponsored by the United States-Canada International Joint Commission. Its primary use was the simulation of the impact of various land uses on NPS pollution load to the Great Lakes.
Process	Continuous/storm events.
Scale	Urban and agricultural watersheds.
Components	
Hydrology:	It uses a deterministic watershed model that simulates infiltration by the Holton or Phillip models, and runoff by the method of the Unit Hydrograph. It also accounts for snow melt and accumulation.
Quality:	It uses a modified Universal Soil Loss Equation to determine surface erosion and evaluate the sediment-adsorbed pollutants.

Other Characteristics — Up to 25 land uses can be evaluated at the same time. It can be applied to a watershed of up to 1000 ha in size.

Nonpoint Simulation Model (2-NPS)

Development — This model was developed by Hydrocomp Inc. to simulate nonpoint source pollution from five different land uses with up to five chemicals from each land use and to account for snow accumulation and melt.

Process — Continuous/storm events.

Scale — Urban and agricultural watersheds.

Components

Hydrology: It uses LANDS submodel similar to the ARLM and HSP models.

Quality: It uses the Negev model for erosion and sediment. Chemical losses are computed using loading functions and potency factors.

Other Characteristics — It is a distributed parameter model. It was tested successfully on small and medium size watersheds.

Hydrologic Simulation Program - FORTRAN (3-HSPF)

Development — This model was developed for the U.S. EPA. It is a comprehensive package for simulating watershed hydrology and water quality for both conventional and toxic organic pollutants.

Process — Continuous.

Scale: Complex watershed.

Components

Hydrology: (See ARM and NPS models).

Erosion and Transport: It uses power functions of rainfall intensity and flow to simulate detachment and transport processes.

Quality: The water quality algorithms in HSPF include BOD/DO, carbon, nitrogen and phosphorus cycle, suspended and attached phytoplankton and one species of zooplankton.

Other Characteristics	This model incorporates the ARM and NPS models and include pollutant transport in channels.

Other Surface Water Models (Supporting Models)

Several other related models include:

1. QUAL 2E: Enhanced Stream Water Quality is a steady state surface water model for conventional pollutants in one dimensional streams and well-mixed lakes. The pollutants included are conservative substances, temperature, bacteria, dissolved oxygen, nitrogen, phosphorus, and algae. It is widely used for waste load allocations and discharge permit determinations.

2. WQA: Water Quality Assessment is a screening procedure for toxic and conventional pollutants in surface and ground water. It is a collection of applicable mathematical expressions, tables, and graphs that can be used as a preliminary assessment tool for developing management programs for surface and groundwater quality in large river basins.

3. WASP: This is a generalized modeling system for contaminant fate and transport in surface waters. It can be appiied to BOD, DO, nutrients, bacteria, and toxic chemicals.

4. EXAMS II: Exposure Analysis Modeling System is a steady-state and dynamic model that can be used for evaluating the behavior of synthetic organic chemicals in lakes, rivers and estuaries.

5. MINTEQ: The Equilibrium Metals Speciation Model is a geochemical model developed to calculate equilibrium aqueous speciation, adsorption, gas phase partitioning, solid phase saturation states, and precipitation and dissolution of 11 metals. It is advised that for proper application of this model, experienced and knowledgeable users are needed.

6. DYNTOX: This is a waste allocation program based on a probabilistic dilution technique to estimate concentrations of toxic substances and effluent toxicity. It includes three types of simulations: continuous, Monte Carlo, and log normal.

7. PRZM: The Pesticide Root Zone Model simulates the vertical movement of pesticides in insaturated soils around the plant root zone.

Table 2-1. Land Use - Pollutants Matrix and Available Loading Functions

Land Use	Pollutant	Availability of Data
Agriculture	Sd, N, Ph, P, BOD, M	High
Irrigation Return Flow	TDS	Medium
Silviculture	Sd, N, Ph, BOD, M	Low
Feed Lots	Sd, N, Ph, BOD	Medium
Urban Runoff	Sd, N, Ph, P, BOD, TDS, M, Coliform	High
Highways	Sd, N, Ph, BOD, TDS, M	Low
Construction	Sd, M	Low
Terrestrial disposal	N, Ph, TDS, M, (others)	Low
Background	Sd, N, Ph, BOD, TDS, M, Radiation	Medium
Mining	Sd, M, Radiation, Acidity	Low

Sd: Sediment
N: Nitrogen
Ph: Phosphorus
P: Pesticides
BOD: Biochemical Oxygen Demand
TDS: Total Dissolved Solids
M: Heavy Metals

Table 2-2. Sediment Yield From Agricultural Land

<u>Universal Soil Loss Equation</u>:

$$A = R * K * SL * C * P$$

where: A = Soil Loss in Tons/Ha
R = Erosivity Factor
K = Soil Erodability Factor
SL = Slope-Length Factor
C = Cropping Management
P = Erosion Control Practice Factor

<u>Sediment Generation Model</u>:

$$A(t) = (1-cov) * K * P(t)^{n}$$

where: A = Sediment Production
cov = Vegetal Cover
K = Soil Property Factor
P = Precipitation
n = Exponent
t = Time

$$T(t) = K * ST * (t-1) * Q(t)^{n}$$

where: T = Sediment Transport
K = Transport Coefficient
ST = Sediment Available for Transport
Q = Overland Flow
n = Exponent

<u>Delivery Ratio Method</u>:

$$T = (DR) * A, \quad DR = a * (DA)^{n}$$

where: T = Sediment Transported
DR = Delivery Ratio
A = Erosion Value
DA = Basin Drainage Area
a = Correlation factor
n = Exponent

Table 2-3. Chemical Pollutants From Agriculture

Loading Functions:

$$L(i) = P(i) * S$$

where: L = Pollutant Load delivered to a receiving water body
P = Potency factor
S = Sediment load
i = Pollutant i

Potency Factor:

$$P(i) = E(i) * C(i) * R$$

where: E = Enrichment ratio
C = Concentration of pollutant in soil
R = Selective erosion factor

For Pesticides:

$$E(i) = a * C(i)^n$$

where: a = Extraction coefficient
n = Exponent describing the effect of selective erosion

Table 2-4. Factors That Influence Nonpoint Source Pollution From Urban Areas

(1)	Population density
(2)	Degree of impervious areas (usually correlated with population density)
(3)	Vegetation cover
(4)	Street litter accumulation rate/street condition
(5)	Traffic density
(6)	Curb density and height
(7)	Street cleaning practices
(8)	Surface storage
(9)	Delivery ratio
(10)	Hydrologic factors
(11)	Geographic factors
(12)	Density of construction sites

Table 2.5 Loading Functions for Urban and Related Areas

Solids:

$$S = R * L(st)$$

Where: R = solid load rate
$L(st)$ = street curb length

Statistical Relations for Sediment Yield:

$$\log S = a + b * S_L - c * C$$

Where: S_L = average slope (%)
C = total construction areas with adequate sediment control
a,b,c = correlation coefficients

Mitre Sediment Yield Formula:

$$Sd = D^{-0.22}$$

Where: Sd = delivery ratio
D = overland distance between the erosion site and the receptor water

Other Pollutants:

$$T = a * S * C(i)$$

Where: C = concentration of pollutant in solids
a = correlation coefficient

Road Traffic:

$$T(tr) = D(i) * L * (TD) * AX$$

Where: D = deposition rate
L = length of highway
TD = traffic density
AX = average number of axles per vehicle

Table 2-6. Summary of Nonpoint Source Pollution Models

	Surface Discharges	Groundwater Discharges	Erosion/ Sediment Transport	Pesticides	Organic Matter	Nutrients	Organic Chemicals
A. AGRICULTURE AND RELATED AREAS							
1. PTR: Pesticides Transport and Runoff Model	X		X	X			
2. ARM: Agricultural Runoff Management Model	X		X	X		X	
3. ACTMO: Agricultural Chemical Transport Model			X	X			X
4. CREAMS: Chemical, Runoff, and Erosion from Agricultural Management System Model	X		X	X		X	
5. GLEAMS: Groundwater Loading Effects of Agricultural Management Systems		X	X	X			
6. AGNPS: Agricultural Nonpoint Pollution Model	X		X		X	X	X
B. URBAN AND RELATED AREAS							
1. STORM: Storage, Treatment, and Overflow Model	X		X			X	
2. SWMM: Stormwater Management Model	X		X				X
C. MIXED AND COMPLEX WATERSHEDS							
1. LANDRUN: Overland Flow and Pollution Generation Model	X		X				
2. NPS: Nonpoint Simulation Model	X		X				X
3. HSPF: Hydrologic Simulation Program - FORTRAN	X		X		X	X	X
D. OTHER SURFACE WATER MODELS (SUPPORTING MODELS)							
1. QUAL2E: Enhanced Stream Water Quality	X		X		X	X	
2. WQA: Water Quality Assessment	X	X	X		X	X	X
3. WASP:	X		X		X	X	X
4. EXAMSII: Exposure Analysis Modeling System	X						X
5. MINTEQ: The Equilibrium Metals Speciation Model	X						
6. DYNTOX:	X						X
7. PRZM: The Pesticide Root Zone Model		X	X	X			

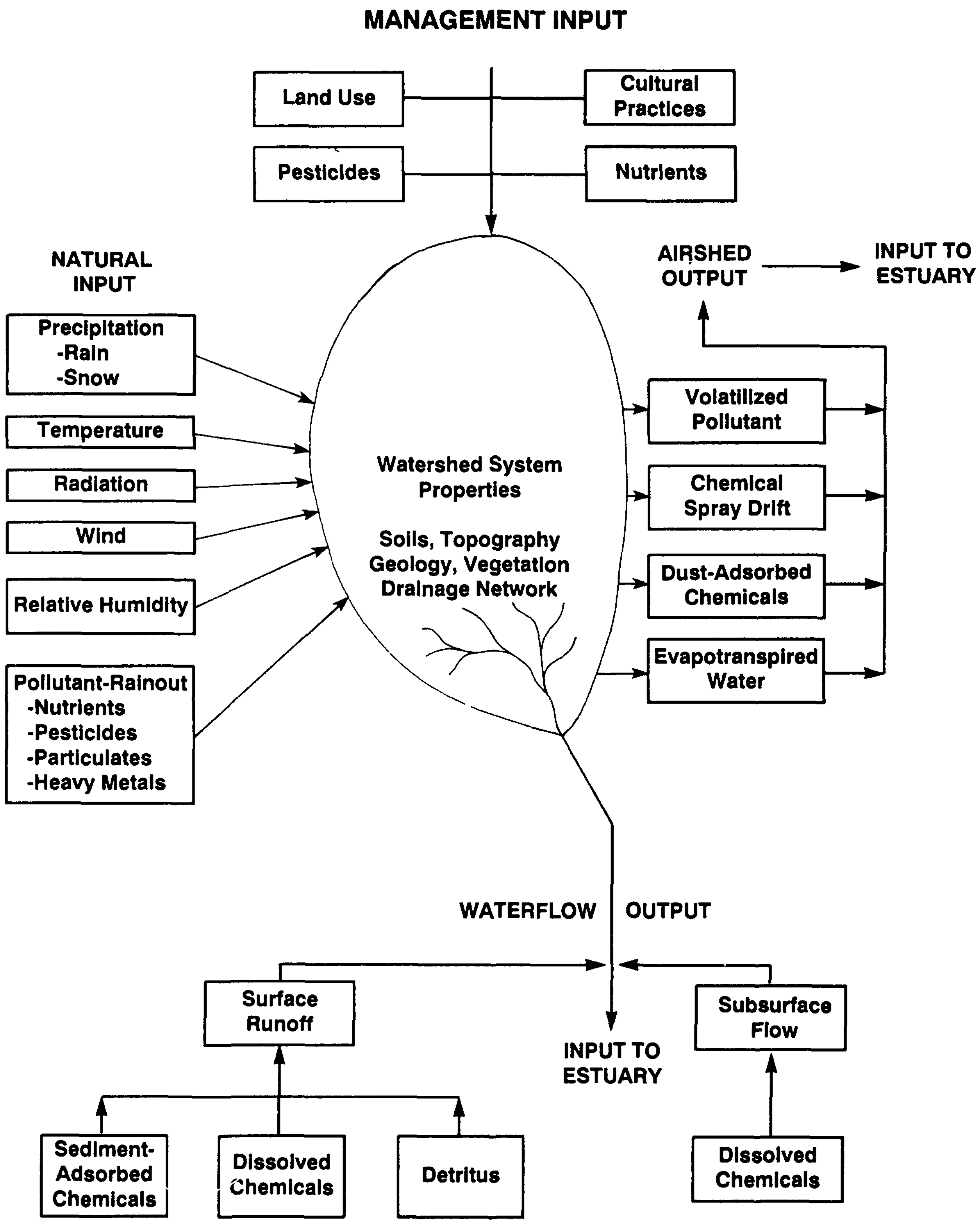

Figure 2.1: Factors influencing the behavior and export of agricultural chemicals from an agricultural watershed (Bailey and Swank, 1983).

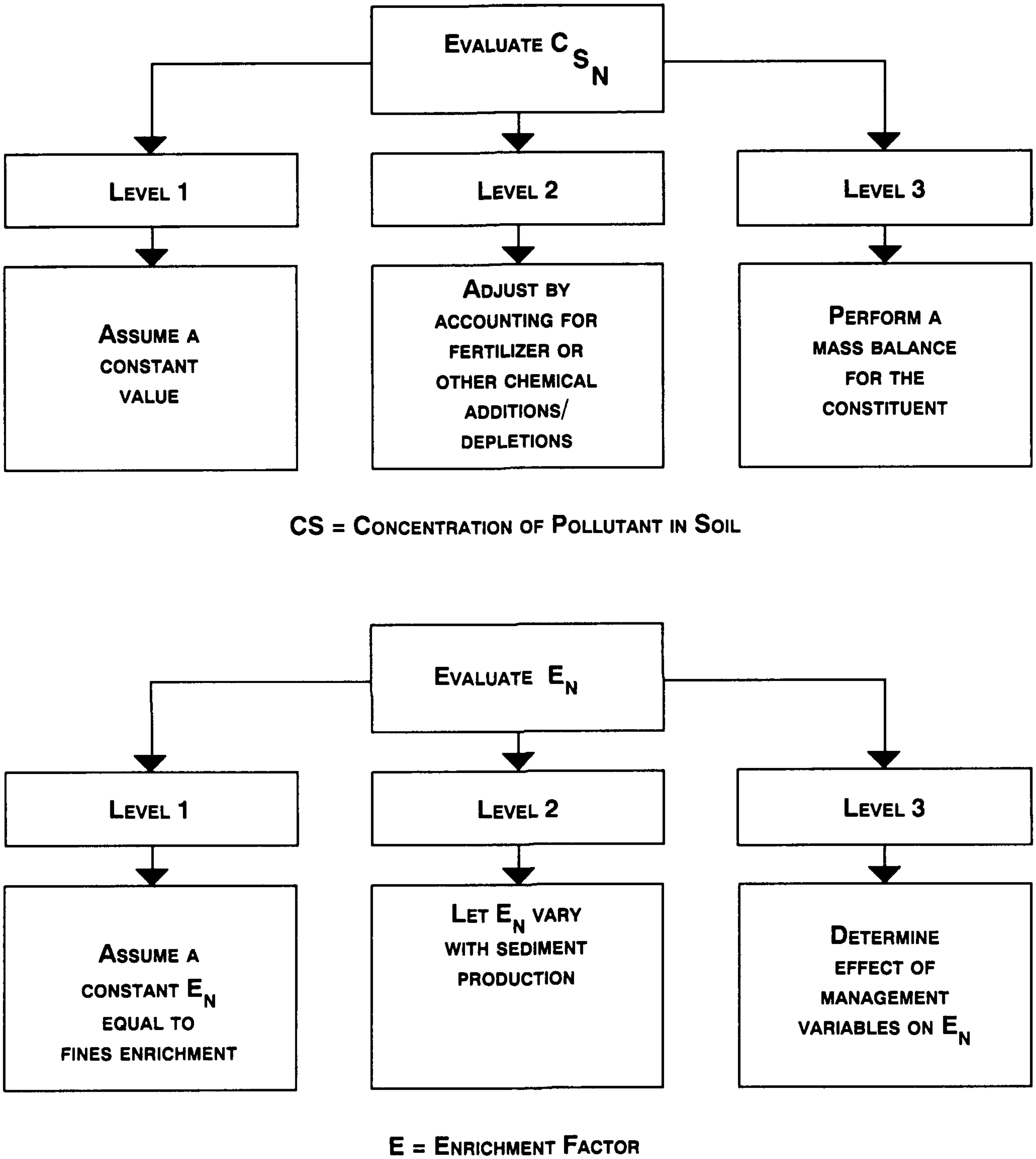

Figure 2.2: Evaluation of potency factors by level of accuracy desired. (Dean, Hudson, and Mills, 1983)

CHAPTER 3

GEOGRAPHIC INFORMATION SYSTEMS FOR NPS ASSESSMENT

A geographic information system (GIS) is a way of storing, analyzing, and presenting areal information. At the heart of the GIS is a data base, which may contain multiple "layers" of data over the same area. Examples of layers could include topographic data, land use/land cover information, hydrologic data, erodibility indices, etc. All layers are referenced to a common ground datum point and orientation, allowing them to be, in essence, overlaid.

Data input to a GIS can be by either analytical or digital means. An example of the former would be map digitizing, while the digital input might be from satellite imagery tapes. One of the great benefits of using a GIS is the collating of data from diverse sources into a consistent form, so that paper maps, aerial photographs, satellite multiband images, etc. may be input by the most convenient method. Regardless of original scale and format, the data, once in the GIS, are consistent; they may be output in different forms for checking; and they are available for a variety of analyses.

Many types of analyses are possible within a GIS, among which are mathematical combinations of layers, Boolean operations, and with external programs using the GIS as a data base, complex simulations.

Individual layers within the GIS could, for example, contain the components of the Universal Soil Loss Equation (USLE), one layer with soil type, another with precipitation, etc. Mathematical combinations of layers would determine soil runoff for every location within the area of interest by multiplying the component values together.

The use of Boolean operations can be readily performed. Various areas that satisfy certain conditions can be entered into the GIS. For example, all areas of coniferous forest within one kilometer of a road, but more than 500 meters away from a lake of greater than 10 hectares can be identified with one set of commands.

Complex simulations are just an extension of mathematical combinations, in which preparation of data for models, and presentation of results, is performed using a GIS. In some cases, the model equations could be incorporated in the GIS software.

Another great advantage of a GIS is the ability to perform sensitivity, or "what-if," analyses. For example, in the Boolean operation described earlier, if an investigator wanted to look at the effects of changing the lake-size criterion, that can be achieved with one additional command. Similarly, if adequate data have been input, the forest specification could be narrowed to a particular species, or a certain stand maturity.

Finally, the structure of a GIS enables the user to maximize the effect of results presentation. By storing all layers in a common format based on areal distribution, maps of input values, intermediate results and final products may all be generated at the same scale and orientation for clarity of analysis.

TYPES OF GISs

There are two types of Geographic Information Systems (GISs), depending on the method of data storage. These will be described briefly.

In raster-based GISs, the area of interest is divided into grid cells, or pixels, and each pixel has a single value for each layer in the data base. The data is stored in the computer as a point which makes up the raster, the image one sees on the computer monitor screen. Thus, a given cell (areal location) could have a value of 6 in the land cover layer, meaning grassland, a value of 3 in the soil type layer, representing silty clay loam, and a value of 3.2 in the percent slope layer. Raster-based GISs are suited to input of digital data, such as satellite imagery. A commonly used example of this type of image processing and Raster-based GIS would be ERDAS (Earth Resource Data Analysis System, Inc).

In vector-based GISs, entities are stored as points, lines, or polygons within a given layer. Thus, an area of open land would be described by the vectors constituting its boundaries; a stream would be described by its linear course. This type of data base is better suited to analog input, such as topographic sheets. One example of a vector-based GIS is Environmental Systems Research Institute's ARC-INFO.

Regardless of the data base structure, either type can accept data in analog or digital form. These data are then converted, as appropriate, into the correct form for storage. The quality of output is generally higher with vector-based systems, since users are accustomed to seeing maps drawn with lines, rather than dots; but these systems are often slower than an equivalent sized raster-based GIS, because of the greater complexity of data manipulation in a vectorized system.

REMOTE SENSING

Remote sensing is the technique whereby the observer takes measurements of electromagnetic radiation, typically (for use with GIS) visible light, infrared, or microwaves. Commonly used remote-sensing tools include aerial photographs and satellite images. As an example, a satellite might take four images of the same scene, capturing four different wavelengths. These would be input to a GIS as four separate layers which could then be combined, contrasted, or compared to derive information about the ground conditions imaged.

Since 1984, the Tennessee Valley Authority (TVA) has been using remotely-sensed data to identify and inventory nonpoint source pollution. Some 11,900 mi^2 of the 91,000 mi^2 TVA region (13 percent) has been surveyed with large and medium scale color infrared aerial photographs, at a cost of only \$40 to \$150 per mi^2. These images have been used to locate and identify septic tanks believed to pollute reservoirs, major sources of animal wastes, mine erosion, and areas containing residual chemicals.

One specific study reported was the rehabilitation of Bear Creek, Alabama, which was closed to recreation in 1984 because of bacterial contamination. The TVA used 1:24,000 aerial stereograms to locate 226 livestock operations and their surface drainage connections in the 70,000-acre Bear Creek watershed. Each was classified according to animal type, apparent treatment system, and estimated severity of waste runoff problem. The TVA identified 70 possible sources of significant amounts of pollution and used monitoring equipment around those sites to verify their findings.

The TVA is also preparing an atlas of annotated overlays of false-color infrared stereograms on 7.5-minute topographic sheets and small-scale aerial photographs. The overlays include agricultural fields, crop cover, animal waste sites, and drainage patterns. Some of these overlays have been input to a computerized GIS, both centrally and distributed on microcomputers to allow on-site management of nonpoint source pollution problems. As a result of these remote surveys, the TVA has identified priority areas within the Authority region at a very moderate cost. These priority areas are: inventories of potential NPS sources including livestock operations, cropland, construction sites, and mine lands; septic systems; groundwater basins, springs, and recharge areas; and urban drainage patterns and land use changes.

The approach taken by the TVA indicates several ways in which remotely-sensed data can be used to identify possible sources of NPS pollution, how much pollution might be transported, and where it might therefore have an effect. Each step is of critical importance in attempts to manage nonpoint source pollution.

USE OF GEOGRAPHIC INFORMATION SYSTEMS IN NPS STUDIES

One important use of GISs is the conversion of linear models to large-scale, areal representations. Not only does this approach allow quantification of, for example, total pollutant loads within an area, but also identification of areas that are particularly important or critical, in terms of a pollutant. In addition, as mentioned previously, sensitivity modeling can be accomplished with a minimum of effort.

Steps to be taken in the use of a GIS to analyze NPS pollution might include:

1. Identify the NPS pollutant of interest.

2. Determine areas of interest with respect to that pollutant.

3. Apply the relevant analytical model(s) to project pollution loading.

4. Classify areas within the project boundary in terms of pollutant loading.

5. Analyze the project area both quantitatively (e.g., total load) and qualitatively (significant sources and routes).

6. Map results for presentation.

7. Conduct sensitivity analyses to determine what Best Management Practices (BMPs) will have greatest impact and where those BMPs should be implemented.

Once the BMP has been selected, one can modify the pollutant load from the area, redetermine the total pollution and areal distribution, produce new maps, and compare them to previous maps. The process of trying various BMPs for various areas can be repeated until water quality in the receiving water has improved to acceptable levels.

GISs and remote sensing have been used in a number of nonpoint source pollution assessment projects, especially in the area of soil erosion. The principles that apply in these studies can be extended to other areas of nonpoint source pollution.

FACTORS TO CONSIDER

The nonpoint source pollutants include sediment, nutrients, and toxic chemicals. Sources and transport routes include soil, water, and air. All combinations of these can be analyzed using GISs. Furthermore, point sources can be superimposed on the system, to enable the user to determine relative point/nonpoint load ratios. These can be particularly useful when determining the economic benefits of nonpoint source pollution controls.

CASE STUDY -- DANE COUNTY, WISCONSIN

One case study of the use of a GIS to manage nonpoint source pollution from agricultural land is presented by Ventura, et al. (1988). The Wisconsin State Legislature mandated the creation of county land conservation committees (LCCs) in 1982 to formulate soil erosion control plans, among other duties. These plans were to include the following information:

a. Specify maximum acceptable rates of soil erosion.

b. Identify location and ownership of noncomplying parcels of land.

c. Identify land-use changes and management practices required to bring such parcels into compliance.

d. Specify procedures to assist land owners in controlling erosion.

e. Establish priority areas.

Dane County, Wisconsin, established a land information system (which is simply another name for a GIS) to aid in formulating a county plan. In addition to meeting this goal, when the Food Security Act was passed in 1985 the GIS was used to implement aspects of the Act with little or no additional technical effort or investment, illustrating the flexibility and utility of geographic information systems.

Soil Erosion Estimates

The universal soil loss equation (USLE) was implemented with polygon overlays (the GIS used was vector-based) and FORTRAN programs. The first step was construction of a digital soil map for the whole county from 181 detailed soil maps. Associated USLE parameters such as soil erodibility, slope length and steepness, and tolerable soil loss were input for the GIS. From these data, the system created maps of soils subject to wind erosion and soils classified according to an erosion index. All highly erodible areas were highlighted.

Land Ownership Data

Because of limited resources, a digital parcel layer was input for only three townships, with the rest of the county being divided on a quarter-section basis and using manual ownership overlays. Ideally in a study of this kind, the additional, manual, step would be removed by expanding the digital ownership data.

Land Cover Data

Land cover, classified as woods, water, row crops, hay/meadow, and other, were input directly from Landsat Thematic Mapper satellite images. Urban and wetland cover types were input from different sources. All cover types except for row crop and hay/meadow were then excluded from analysis.

Modeling

Digital land cover and soil type maps were overlaid in the GIS to obtain areal "units of analysis." Input errors were analyzed and the USLE was calibrated on the basis of field observations. FORTRAN models were used, with the data from the GIS units of analysis, to calculate soil losses and the effects of conservation practices and crop rotation.

Results

The first data product was a county-wide map of estimated soil loss in tons per acre, on a half-section basis. Other maps produced by the system included the ratio of annual/tolerable soil loss (A/T ratio); the calculated CP factor (cropping and conservation practices) required to make the A/T ratio acceptable; and cropland eligible for the Conservation Reserve Program. Another useful feature of the GIS is that the Conservation Reserve Program eligibility map can be updated rapidly as the rules change. Additionally, the system determined statistics on the average soil loss rate, amount of land in each A/T category, etc.

This case study illustrates that a GIS, perhaps in conjunction with some form of analytical model, is well suited to analyses of nonpoint source pollution and relevant BMPs.

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

The objective of this study was to identify computer and geographic information system methods for modeling the water pollution potential of nonpoint discharges.

Based upon the findings, the following conclusions and recommendations are provided.

CONCLUSIONS

The selection of a tool to quantify pollution loads from nonpoint sources depends on many factors, including cost, level of accuracy, ease of use, and availability. It has been noted that these available tools are very specific and cannot be used in all conditions, for example, they are pollutant, pollutant process, and land use specific. Additionally, the uses of these tools are, in many cases, valid only in the given geographic areas for which they were developed. Each user will need to weigh these factors to determine the best tool for their needs.

Loading functions are the least expensive and easiest to use tools. For initial prioritizing of nonpoint source pollution, loading functions can provide a quick answer using limited data. Loading functions represent very rough estimations and care must be taken to ensure that their use is undertaken with caution. The interpretation of results need to be made by experienced staff.

Many loading functions are available for quantifying pollution loads from agricultural and typical urban areas. The Navy can use these loading functions for assessing pollution from out-leased agricultural areas, housing areas, and commercial/office areas on base. The initial assessment using loading functions can help in prioritizing which areas need further characterization through computer modeling and sample analysis to determine if mitigative actions are needed.

No loading factors exist for industrialized areas, impact areas, rifle ranges, demolition areas and similar areas. Loading factors need to be developed to assist in assessing pollution loads and initial prioritizing.

The use of computer simulation models can provide more accurate assessment of pollution loads from a NPS. However, compared to loading functions they are data extensive and can be both costly and time consuming. They also require specially trained personnel to input the data into the model and to run the program. Generally, the use of these models has been limited to aiding in setting water quality objectives in an area and selecting the best management programs to meet water quality objectives.

Eighteen different computer models are identified for quantifying the pollution loads from agricultural and urban nonpoint sources. Considerable effort has been made in developing models to assess sediment, nutrient, and pesticide pollution from agricultural areas. Models for assessing pollutant loads from urban areas primarily address storm water runoff volume and conventional pollutants such as BOD, nitrogen, phosphates, and sediment. No computer model exists that can accurately assess toxic chemical pollution from industrial areas. One model can assess up to five chemicals from each land use, but it appears to be not very accurate as it uses loading functions to estimate pollutant loadings.

Selection of a model will depend on the accuracy desired, pollutants to be predicted, land size and use, model availability, data availability, and cost. The Navy should consider using these models where more accurate determination of pollutant loads is needed from an agricultural out-leased area or nonindustrialized on base areas, such as housing areas and commercial/office areas.

No accurate computer models exist for industrialized areas, impact areas, rifle ranges, demolition areas and similar areas. Computer models need to be developed to assist in assessing pollution loads and to determine what type of mitigation measures, if any, are needed to control NPS from these areas.

GIS systems provide the ideal platform to run NPS computer models. The Navy should consider using a GIS system in several instances. If an activity has a GIS system with topographical and land use capability, using the GIS system to run a NPS model greatly reduces data input and setup time. Also, it is easy to make "what if" changes to land use and assess the impact on NPS pollution. This is especially helpful in the project planning stages. Another case where a GIS system can reduce data input time and cost is for assessing pollutant loads from large land areas such as training areas and impact areas. Instead of manually entering geographic information into a computer model, readily available digitized geographic data from aerial photographs and satellites can be automatically fed into the GIS system. Data input time and associated costs are greatly reduced.

RECOMMENDATIONS

Initiate Use of Loading Functions and Computer Models

Loading functions and computer models exist for aiding in the assessment and prioritization of NPS pollution from many Navy land areas. These include out-leased land areas and nonindustrialized on-base areas such as housing areas, office areas, and commercial areas. The use of the loading functions and computer models are recommended to reduce sample collection and analysis requirements in many cases. Where a GIS system exists for a base or if a large land area is being assessed, the GIS system should be used to further reduce assessment costs. The relative impact of nonpoint source pollution can be compared with point source pollution to aid in prioritizing what actions need to be taken to reduce water pollution from a base(s). The use of these loading functions can help in the project planning stage to help in identifying mitigative measures to reduce NPS.

Develop Loading Functions and Computer Models for Navy Unique Areas

Loading functions and computer models do not exist for training areas, impact areas, rifle ranges, ordnance demolition areas, and Navy industrial areas. We recommend the development of loading functions and computer models for sources not already addressed by the EPA or academia. In some cases, existing loading functions and computer models can be easily modified for use in these areas. In some cases, more field data may need to be gathered to help in formulating loading functions and computer models. In all cases, the loading functions need to be tested before transferring to routine Navy use.

CHAPTER 5

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APPENDIX

ADDITIONAL INFORMATION ON LOADING FUNCTIONS AND LOADING FACTORS

LOADING FUNCTIONS

In order to quantify and solve a diffuse contamination problem in a region due to nonpoint source pollution, it is important to understand how this occurs, and one way to achieve this is through the use of models. A loading function, also known as a loading model, is a mathematical expression which can be used to calculate the emission of a pollutant from a nonpoint source and the discharge of the pollutant into surface waterways. There are basically two approaches to modeling nonpoint source pollution: (1) lumped parameter models; and (2) distributed parameters models. The first one treats a watershed or a considerable section of it as a unit. Different characteristics of the watershed are lumped together, usually with an empirical equation to represent the modeled unit as a uniform system. The coefficients for each unit are obtained by calibrating the model output with respect to field data. The distributed parameter models divide a watershed into smaller homogeneous units with uniform characteristics. Each single unit is modeled independently and the final output is determined by adding every individual output.

Models can also be classified as either continuous or discrete. Continuous modeling sequentially simulates different processes operating on a time interval ranging from a day to minutes, and constantly balances water and pollutant mass in the system. Discrete models simulate the response of a watershed to a major rainfall or snowfall snow-melt. Models can be further classified with respect to their structure. They can be found as either simple statistical unit loadings that express long-term loadings related to land use and other aerial characteristics; or deterministic time variable models, these models are basically a description of the hydrologic rainfall runoff transformation process with quality components attached.

It must be understood that mathematical models are only a rough approximation, and that the accuracy and reliability of them are limited. Generally for any model, three sets of data are needed: (1) system parameters, for instance, watershed size, slope, soil characteristics, crops and vegetation, etc.; (2) state variables, for example, ambient temperature, adsorption/desorption coefficients, accumulation rates of litter, strength of pollutants, etc.; and (3) input variables such as precipitation, evaporation rates, etc.

EXAMPLES OF LOADING FUNCTION MODELS

Sediment from Sheet and Rill Erosion

Sediment produced by soil erosion is one of the greatest nonpoint source pollutants. The sediment reduces water quality; thus recreational and consumptive use values are decreased. It occupies space for water storage in reservoirs, lakes and ponds; restricts streams and drainage ways; and alters aquatic life. But more importantly, sediments also carry other water pollutants such as nitrogen, phosphorus, organic matter, pesticides, pathogens, etc.

Sheet erosion is the uniform removal of a thin layer of soil, generally by the impact of raindrops. Rill erosion is the removal of soil by small amounts of surface water, as for example those found between rows of cultivated crops.

The Universal Soil Loss Equation (USLE) is a basic tool and most common estimator of soil erosion. Extensive data is available for factors included in the model. The loading function is as follows:

$$Y(S)_E = A * (R * K * L * S * C * P * Sd)$$

where: $Y(S)_E$ = sediment loading

A = source area

R = rainfall factor

K = soil erodibility factor

L = slope length factor

S = slope gradient factor

C = cover factor

P = practice factor

Sd = sediment delivery ratio

Nonpoint source loading models are part of nonpoint source simulation models, which address inputs and movement of materials from their point of origin to water courses.

Nutrients and Organic Matter

The primary nutrients from agricultural practices are nitrogen and phosphorus; they are important pollutants if discharged in a water body due to their great potential for algae blooms in lakes. Algae blooms can interfere with many beneficial uses of water. The losses of nitrogen and phosphorus from various land areas can be calculated by making nutrient budgets of all inputs and outputs. Organic matter from agricultural activities can degrade the quality of receiving water by depleting its oxygen content and by increasing the potential of pathogenic microorganism contamination.

One method for estimating nutrient and organic matter loadings is based on calculating sediment yields and modifying them by factors which represent concentrations of these pollutants in the soil.

In addition to sediment-carried nitrogen, nitrogen carried in rainfall can be addressed as follows:

$$Y(NT)_E = a * Y(S)_E * C_s\ (NT) * r_n$$

$$Y(N)_{Pr} = A * \left(\frac{Q(OR)}{Q(Pr)}\right) * N_{Pr} * b$$

$$Y(NT) = Y(NT)_E + Y(N)_{Pr}$$

$$Y(NA) = Y(NT)_E * fN + Y(N)_{Pr}$$

where: $Y(NT)_E$ = total nitrogen from erosion

$Y(S)_E$ = sediment load

$Y(N)_{Pr}$ = nitrogen from rainfall, discharged to streams

NT = sum of nitrogen of all chemical forms

A = area of source

r_n = enrichment factor

NA = available nitrogen

fN = ratio of NA to NT in sediment

a = dimensional constant

b = attenuation factor

Np_r = rate of deposition of nitrogen from the atmosphere in precipitation

$C_s(NT)$ = concentration of nitrogen in soil

Q(OR) = overland runoff

Q(Pr) = total precipitation

The loading function for phosphorus can be expressed as the product of the sediment yield times the phosphorus concentration in the sediment, times an enrichment factor. The load of available phosphorus is calculated as:

$$Y(PT) = a * Y(S)_E * C_s(PT) * r_p$$

$$Y(PA) = Y(PT) * f_p$$

where: $Y(PT)$ = yield of total phosphorus

a = dimensional constant

$C_s(PT)$ = concentration of phosphorus in soil

r_p = enrichment factor

$Y(PA)$ = yield of available phosphorus

f_p = ratio of available phosphorus

Generally, organic matter loading functions are expressed as a function of sediment yield, thus the yield of organic matter is a product of the sediment yield and organic matter concentration in sediment multiplied by an enrichment factor; therefore:

$$Y(OM)_E = a * C_s (OM) * Y(S)_E * r_{OM}$$

where: $Y(OM)_E$ = organic matter loading

$Y(S)_E$ = total sediment loading from surface erosion

r_{OM} = enrichment factor

a = dimensional constant

$C_s(OM)$ = organic matter content of soil

Pesticides

Pesticides dissipate by several mechanisms. Losses by leaching processes and by over ground transport mechanisms are the most important with respect to water contamination. The fraction of pesticides transported overland may be estimated if runoff is measured and analyzed for pesticides. Specifically, hydrographs must be determined, and concentrations of pesticides at various points of the hydrograph must be taken. The data obtained is converted to pesticide loadings by multiplying increments of flow by the respective concentration values. If no data is available a sampling program could be performed in the region of concern. Therefore, the loading functions are as follows:

$$Y(HIF) = S_i * Q_i * C_i * a$$

where: $Y(HIF)$ = total pesticide loading for source

Q = runoff volume

C = concentration in runoff

i = storm event

a = dimensional constant

Irrigation Return Flow

The precise prediction of salinity emissions due to irrigation return flows requires knowledge of the system being studied, because it varies widely depending on the region due to soil type, geological formations, topography, irrigation practices, etc. The method for estimating salinity loads from irrigation return flows involves a stream to source approach. Salinity loads in streams are determined above and below areas of irrigation. Differences in salinity loads represent the total salt being discharged by the area by background and point sources, as well as irrigation return flow. Therefore, loadings from this source are determined by substracting contributions from background and from point sources. Therefore,

$$Y(TDS)_{IRF} = a * Q(str)_B * C(TDS)_B - Q(str)_A * C(TDS)_A$$
$$- Y(TDS)_{BG} - Y(TDS)_{PT}$$

where: $Y(TDS)_{IRF}$ = yield of salinity in irrigation return flow, kg/day

$Y(TDS)_{BG}$ = salinity load contribution of background, kg/day

$Y(TDS)_{PT}$ = salinity load contribution of point sources, kg/day

$Q(str)_B$ = streamflow of surface water below irrigated areas, l/s

$Q(str)_A$ = streamflow of surface water above irrigated areas, l/s

$C(TDS)_B$ = concentration of total dissolved solids in stream below irrigated area, mg/l

$C(TDS)_A$ = concentration of total dissolved solids in stream above irrigated area, mg/l

a = conversion constant

The background total dissolved solids load can be formulated as:

$$Y(TDS)_{BG} = a * A * Q(R) * C(TDS)_{BG}$$

where: $Y(TDS)_{BG}$ = salinity load from background, kg/l

A = area under consideration, ha

$Q(R)$ = flow, as annual average runoff, cm

$C(TDS)_{BG}$ = concentration of background total dissolved solids as determined by local information, mg/l

a = conversion constant

Urban Runoff

Various wastes are picked up by storm water, with these wastes fluctuating from settled dust and ash to debris coming from man himself. The quantities of solids from urban nonpoint sources are quite significant, and within the different urban land uses, the industrial type is of most concern. Fly ash and dust from industrial processes, such as steel mills, cement manufacturing, chemical processes and others, are known to be profuse.

Models that use solids accumulation and composition of solids, and which assess the quality of pollutant loadings, are given as follows:

For solids:

$$Y(S)_m = L(s)_m * L_{st}$$

where: $Y(S)_m$ = daily total solids loadings, kg/day

$L(s)_m$ = daily solids loading rate, kg/curb-km/day

Lst = street curb-length, curb-km

For Other Pollutants:

$$Y(i)m = a * Y(s)m * C(i)m$$

where: $Y(i)_m$ = daily total loading of pollutant i, kg/day

a = conversion factor

$Y(S)_m$ = daily total loading of solids, kg/day

$C(i)_m$ = concentration of pollutant i in solids, mg/g

LOADING FACTORS

Loading factors, also known as unit loadings, are simple factors which can be used to express pollution generation per unit area and unit time for various land uses. The units generally are expressed as kg/ha-yr. Land use is a simple term describing the prevailing activity occurring in an area. Examples of factors which strongly affect pollution generation in urban areas and correlate closely with land use include the following:

Population density

Atmospheric fallout

Degree of impervious area usually correlated with population density

Vegetation cover

Street litter accumulation rates

Traffic density

Curb density and height

Street cleaning practices

Pollution conveyance systems

As can be seen from the above list, there are many factors that correlate with land use. Thus, it can be justified to relate pollution loadings from nonpoint sources to land-use activities. This method, which relates pollution loadings to land use categories, has found wide application in area-wide pollution mitigation and planning due to its simplicity; it provides fast answers to pollutant problems of large areas where, because of the large amounts of information required, more complicated efforts would be almost impractical. This algorithm combined with information on soil distribution, land use, etc. can identify zones with the highest quantities of nonpoint source pollution. As mentioned earlier, the term land use describes the prevailing activity taking place in an uniform geographic area. Urban and rural types of land use are two main categories, although presently, land use inventories have up to 50 categories and subcategories. Because it is not possible to define pollution impacts for each detailed land use category; land uses are gathered into more general sets with certain relationships with respect to pollutant generation. Two land uses are summarized herein; the agricultural, which falls in the rural or non- urban category; and industrial, which is a subcategory of the urban category.

EXAMPLES OF LOADING FACTORS

Agriculture Areas

In agricultural lands many factors affect pollutant emissions. Erosion and irrigation return flows are sources of concern through surface runoff, interflow and groundwater base flow; in these considerations, reducing one component of pollution often results in an increase of others. Based on a review of the literature on loading studies, the use of 0.5 kg/ha/year and 5 kg/ha/year is recommended for the estimation of total phosphorus and total nitrogen loadings, respectively. Tables A-1 through A-7 provide examples of nonpoint pollution loading factors for agricultural activities.

Industrial and Urban Areas

The industrial component of this category can be further subclassified into two subcategories; manufacturing and extractive industrial activities. The manufacturing subcategory ranges from low pollution generating industries to high pollution sources such as steel mills, foundries, cement manufacturing, etc. The main source of nonpoint pollution in most industrial areas is the atmospheric deposition resulting from operations performed in such areas. In addition, disposal sites of industrial wastes represent a source of groundwater contamination.

Somewhat higher phosphate values (about twice as much as agricultural sources) are typical for urban areas; however, many of the urban loadings include contributions from impervious surfaces. Chemical Oxygen Demand (COD) values from urban areas are in the range of 220 to 310 kg/ha-yr; and typical BOD_5 values are from 30 to 50 kg/ha-yr. Total nitrogen loads range from 7 to 9 kg/ha-yr, and total phosphorus loads are from 1.1 to 5.9 kg/ha-yr. Tables A-8 through A-16 show industrial loading factors as well as urban unit loadings.

Table A-1. Agricultural Regional Average Loading Factors

	Mostly Agricultural		Agricultural	
	Phosphorus	Nitrogen	Phosphorus	Nitrogen
North and Northeastern	17	550	25	650
Corn Belt and Dairy Region	22	550	32	950
East and Central	26	800	24	750
Piedmont and Coastal Plain	22	650	46	1400

Units are $kg/km^2/yr$.

Table A-2. Ranges of Unit Loadings in a Pilot Agricultural Watershed Study

(kg/ha-yr)	Suspended Sediments	Total Phosphorus	Total Nitrogen	Lead
General Agriculture	5 - 9000	0.1 - 10	0.9 - 90	0.005 - 0.09
Cropland	30 - 9000	0.3 - 8	8 - 50	0.008
Improved Pasture	50 - 90	0.1 - 0.8	5 - 20	0.005 - 0.02

Table A-3. Average Agricultural Land Use Loadings in the United States

	(Million Tons/Year in the United States)			
	Sediment	BOD_5	N	P
Cropland	1700	8.2	3.9	1.42
Pasture and Range	1190	4.5	2.3	0.98

Table A-4. Loading Ranges for Cropland Water

Drainage	Nitrogen (kg/ha-yr)	Phosphorus (kg/ha-yr)
Irrigation return flow	3 - 30	1 - 4
Subsurface tile drainage	5 - 20	3 - 10

Table A-5. Agricultural Drainage in Black Creek Watershed

Pollutant	Range (kg/ha-yr)
Suspended sediment	30 - 5,100
Total phosphorus	0.2 - 4.0
Total nitrogen	4.3 - 31

Table A-6. Loading Factors for Simulated Midwestern Agricultural Conditions

Soil Type	Sediment (kg/ha-season)			Phosphorus (kg/ha-season)		
	Spring	Summer	Fall	Spring	Summer	Fall
Boyer sandy loam	2,240	560	150	2.22	0.56	0.15
Hochheim loam	4,400	1,280	296	6.6	1.92	0.44
Ozaukee silt loam	13,600	2,400	578	24.4	4.31	0.94
Ashkum silty clay loam	15,000	5,340	800	46.1	16.85	2.50

These loading values are based on the assumptions that the USLE cover factor is C = 0.8 in spring and C = 0.08 in summer and fall and that the soil conservation practice factor is P = 1.0.

Table A-7. Comparison of Erosion Rate and Nonpoint Yields for Representative Watersheds

Watershed	Gross Erosion (kg/ha/yr)	SS (kg/ha/yr)	TP (kg/ha/yr)	SRP (kg/ha/yr)	NO_3 (kg/ha/yr)
Broken Sword	9,390	1,110	1.71	0.23	18.1
Wolf, East	4,190	619	1.14	0.22	17.1
Ratio - Broken Sword: Wolf East	2.24	1.79	1.50	1.04	1.06
Honey Creek	6,860	63	1.23	0.24	15.3
Wolf, East	4,190	619	1.14	0.22	17.1
Ratio - Honey: Wolf East	1.63	1.02	1.08	1.09	0.89
Raisin River	9,750	188	0.44	0.11	8.1
Sandusky River	8,250	673	1.14	0.22	12.5
Ratio - Raisin R: Sandusky R.	1.18	0.27	0.38	0.50	0.65

Table A-8. Street Refuse Accumulation

	Solids Accumulation (gm/curb m/day)	
	Chicago	Eight American Cities
Land Use	Dust and Dirt	Total Solids
Single family	10.4	48
Multiple family	34.2	66
Commercial	49.1	69
Industrial	68.4	127
Average of Above (weighted)	22.3	-

Table A-9. Pollutants Associated with Street Refuse (mg/g of Total Solids)

Constituent	Land Use: Residential	Industrial	Commercial	Transportation
BOD_5	9,166	7,500	8,333	2,300
COD	20,822	35,714	19,444	54,000
Volatile solids	71,666	53,571	77,000	51,000
Total Kjeldahl nitrogen	1,666	1,392	1,111	156
PO_4^-P	916	1,214	833	610
NO_3^-N	50	64	500	79
Pb	1,468	1,339	3,924	12,000
Cr	186	208	241	80
Cu	95	55	126	120
Ni	22	59	59	190
Zn	397	283	506	1,500
Total coliforms (No./g)	160,000	82,000	110,000	NR
Fecal coliforms (No./g)	16,000	4,000	5,900	925

Table A-10. Mean Concentrations of Organic Chemicals in Urban Dust and Dirt (mg/g) Averages of Several United States Cities

Constituent	Concentration	Standard Deviation
Endrin	0.00028	0.00078
Dieldrin	0.028	0.028
PCBs (overall)	0.78	0.76
Methoxychlor	0.50	1.1
Lindane	0.0022	0.0063
Methylparathion	0.0024	0.0073
p,p-DDD	0.082	0.080
p,p-DDT	0.075	0.12
Asbestos	160,000 fibers/g	-

Table A-11. Urban Land-Unit Area Loadings of Total Phosphorus and Suspended Solids

Land Use	Total P (kg/km^2-yr)	Suspended Solids ($tons/km^2$-yr)
	Parameter	
Areas of combined sewer systems:		
High industry	1100	72.6
Medium industry	1000	74.3
Low industry	900	75.9
Areas of separated sewer systems:		
High industry	300	66.0
Medium industry	250	52.3
Low industry	125	38.5
Unsewered areas	125	38.5
Towns of 1000-10,000 people	250	52.3

Table A-12. Urban Regional Average Loading Factors

	Mostly Urban (kg/km^2/yr)	
	Phosphorus	Nitrogen
North and Northeastern	25	700
Corn Belt and Dairy Region	32	650
East and Central	46	1050
Piedmont and Coastal Plains	6	550

Table A-13. Ranges of Unit Loadings in a Pilot Watershed Study

kg/ha-yr	Suspended Sediments	Total Phosphorus	Total Nitrogen	Lead
General Urban	200 - 2000	0.5 - 5	8 - 10	0.2 - 0.8
Residential	900 - 4000	0.6 - 2	7 - 9	0.08
Commercial	80 - 1000	0.1 - 1	2 - 20	0.3 - 1.0
Industrial	800 - 2000	1 - 8	2 - 30	---
Developing Urban	---	15	100	30 - 90

Table A-14. Average Urban Area Loadings in the United States (Million Ton/Yr)

	Sediment	BOD_5	Nitrogen	Phosphorus
Urban Runoff	18	0.45	0.13	0.017
Construction	179	--	--	--
Landfill	--	0.27	0.024	--

Table A-15. Loading Factors in Residential Areas Near the Great Lakes (kg/ha-yr)

Suspended solids	200 - 2300
Total phosphorus	0.4 - 1.3
Total nitrogen	5 - 7
Lead	0.06 (one number only)

Table A-16. Soil Erosion From Construction Zones

Soil Type	Sediment (tons/ha-yr)	Phosphorus (kg/ha-yr)
Boyer sandy loam	11.0	10.9
Hochheim loam	27.5	41.3
Ozaukee silt loam	43.7	78.7
Ashkum silty clay loam	55.6	172.3

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