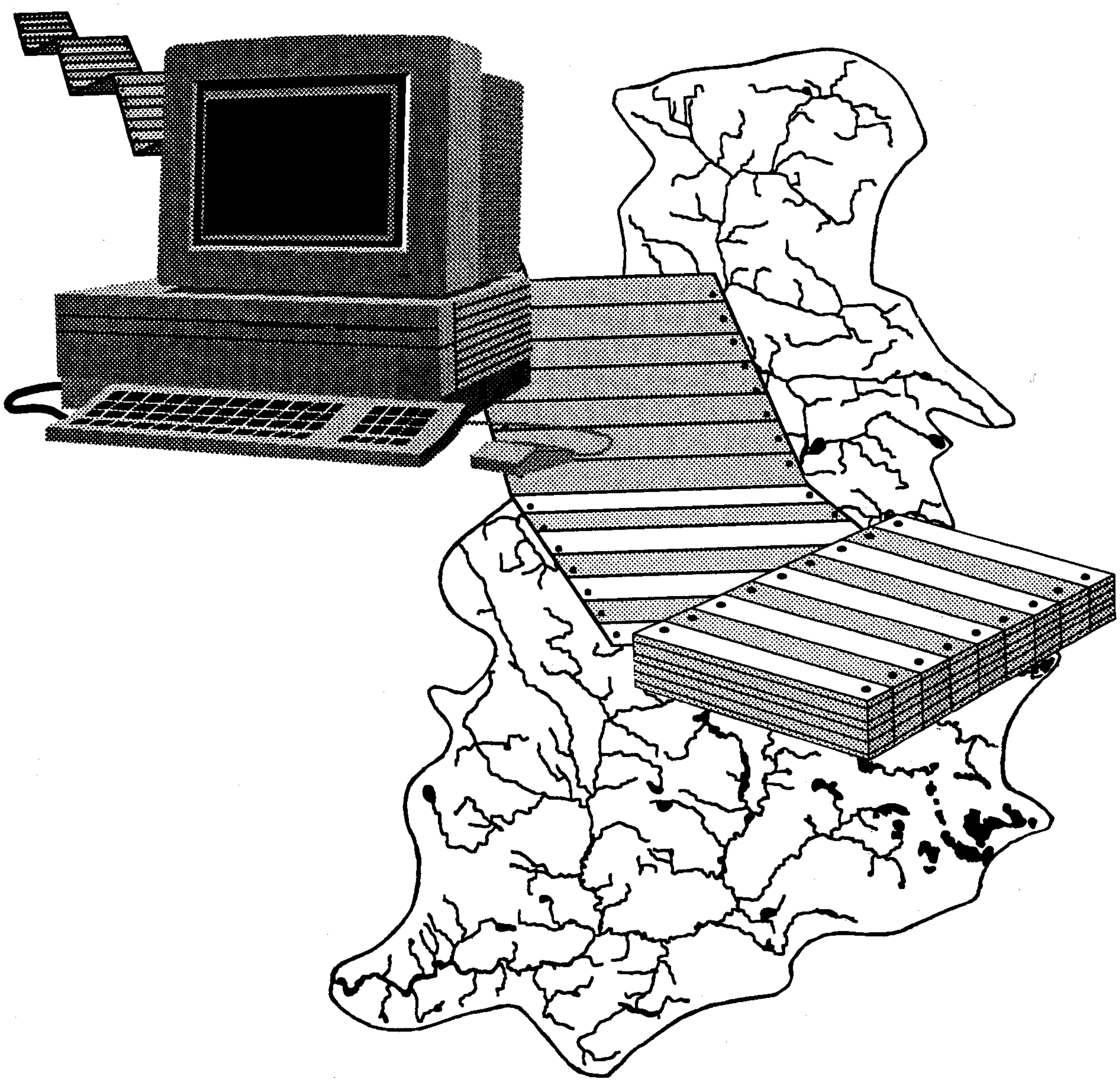
United States
Environmental Protection
Agency

Office of Water
Washington D.C.

EPA841-R-92-002
June 1992

EPA

COMPENDIUM OF WATERSHED-SCALE MODELS FOR TMDL DEVELOPMENT



COMPENDIUM OF WATERSHED-SCALE MODELS FOR TMDL DEVELOPMENT

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Washington, DC 20460

June 1992

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Foreword

The process for determining specific pollution reductions needed to attain State water quality standards under the Clean Water Act is set out in Section 303(d) of that Act and involves the determination of Total Maximum Daily Loads (TMDLs) As interpreted in EPA regulations and guidance, the TMDL process can be used to address large geographic areas such as river basins and provides water quality managers with an analytical method to address more complex water pollution problems, such as nonpoint sources, and to adopt a more integrated approach to water quality management Through recent program initiatives such as the Watershed Protection Approach, EPA has been encouraging Federal, State, and local agencies concerned with water quality management to analyze all water quality problems and stressors, and recommend management measures on a basinwide rather than an individual source basis

This compendium, developed in response to recommendations made at the Workshop on the Water Quality-based Approach for Point Source and Nonpoint Source Controls held in Chicago on June 26-28, 1991, has identified and summarized the most widely used (as well as some of the more obscure) watershed-scale models that can facilitate the TMDL process It is intended to help water quality managers and other potential users decide which model best suits their needs and available resources

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Acknowledgments

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Table of Contents

List of Tables

1. INTRODUCTION AND PURPOSE

Simulation models are used extensively in water quality planning and pollution control Many types of models are available to simulate different environmental phenomena and components of pollution problems For example, there are models to predict the chemical speciation of contaminant metals, the fate and transport of organic compounds, the bioaccumulation of polar compounds, the mixing of wastewater plumes, the eutrophication process, flow and velocity characteristics in channels and the effects on fishery habitat, and so on Historically, the Environmental Protection Agency's (EPA) water programs and its counterparts in State pollution control agencies have focused on pollution problems resulting from wastewater discharges Attention is now expanding to encompass nonpoint source problems and storm-related problems It is also generally recognized that solving these problems requires a "watershed approach" to analyzing the problems, engaging the parties that have a stake in the process, and developing solutions to the pollution problems Examining problems on a watershed scale is a new challenge for which there are not well-developed techniques and models The purpose of this document is to provide the reader with a quick compendium of models that are useful for watershed-scale analysis

1.1 Background

Section 303(d) of the Clean Water Act (CWA) requires States to develop Total Maximum Daily Loads (TMDLs) for water quality-limited waters where existing or proposed controls do not or are not expected to result in attainment and/or maintenance of the applicable water quality standards (WQSs) Implementation of section 303(d) of the CWA has traditionally emphasized point source wasteload allocations, which were easily enforced by incorporating them into National Pollution Discharge Elimination System (NPDES) permits as discharge limits Nonpoint sources were generally not included as a separate component of a TMDL because of the difficulty in measuring water quality impacts and the effectiveness of controls Experience has shown, however, that controlling point source discharges does not necessarily ensure attainment of WQSs, especially when nonpoint sources are a significant contributor to water quality problems

It is time to consider nonpoint sources as distinct from natural background pollutant loadings and to formally address them as a distinct component of the TMDL equation in water quality management schemes Recognizing this fact, EPA is now stressing more integrated water quality management that considers all of the sources and types of pollution within a watershed and brings together all shareholders to develop cooperative solutions

This new focus was clearly stated in EPA's programmatic guidance outlining the TMDL process (US EPA, 1991b) By addressing the technical issues of developing and implementing TMDLs within a broader water quality-based management strategy, this document sets the stage for State and Federal agencies to establish both point and nonpoint source pollution controls on a watershed basis

The water quality-based approach consists of five steps, the first three of which constitute the TMDL process:

1) identification of water quality-limited waters that require TMDLs and the pollutants causing impairment,

2) priority ranking and targeting of identified waters,

3) TMDL development,

4) implementation of pollution control actions, and

5) monitoring and assessment of control effectiveness

In complex situations or where nonpoint source reductions are part of the TMDL, a "phased approach" may be used Under this approach, available knowledge on water quality conditions and BMP effectiveness is used in conjunction with scheduled monitoring and evaluation to develop TMDLs that consider point and nonpoint sources of pollution In fact, the final step of the TMDL process provides for continuous evaluation and improvement of the TMDL and the pollution control actions Models and data analysis techniques may be used in the implementation of each phase of the TMDL process Models can assist in the initial evaluation, ranking and targeting, TMDL development, evaluation of controls, and program tracking

As part of steps 1 and 2, an initial evaluation of water quality may be used to focus or target resources for TMDL development The use of such preliminary screening applications can provide water quality managers with an initial assessment of water quality, pollutant loading, and source determination for key watersheds Screening applications are typically performed with minimal input data and calibration/verification Because of the preliminary nature of the application and data limitations, the accuracy of output is often low The results of screening applications are nevertheless adequate for relative comparisons and preliminary decision making As key watersheds are identified and additional monitoring data are collected, more detailed and accurate model analyses can be initiated

1.2 Classification of Watershed-Scale Models

One challenge faced by water quality managers is the lack of highly developed, scientifically sound approaches to identify problems in watersheds and to predict the results of potential control actions on water quality While a wide variety of models are available, each comes with limitations on its use, applicability, and predictive capabilities The type of study will dictate the complexity of the development of a model to be selected For example, a high-priority water with a number of pollutant sources may require a detailed model analysis In determining where to set priorities and gathering information prior to initiating development of a TMDL, it may be necessary to use several models or portions of models A wide variety of technical tools and techniques are available to evaluate point and nonpoint loads from watersheds containing multiple sources and land uses. Although these tools were not specifically designed to address the TMDL process, many of their capabilities can be directly applied to comprehensive water quality-based assessments.

Existing watershed-scale models can be grouped into three categories - simple methods, mid-range models, and detailed models - based on the number of processes they incorporate and the level of detail they provide In addition to the different classes of models, the level of application of a given model may vary depending on the objectives of the analysis

Simple Methods The major advantage of simple methods is that they can provide a rapid means of identifying critical areas with minimal effort and data requirements

Simple methods are compilations of expert judgment and empirical relationships between physiographic characteristics of the watershed and pollutant export that can often be applied by using a spreadsheet program or hand-held calculator Simple methods are often used when data limitations and budget and time constraints preclude the use of complex models They are used to diagnose nonpoint source pollution problems based on relatively limited available information They may be used to support an assessment of the relative significance of different sources, guide decisions for management plans, and focus continuing monitoring efforts

Simple methods, in general, rely on large-scale aggregation and neglect important features of small patches of land They rely on generalized sources of information and therefore have low to medium requirements for site-specific data Default values provided for these methods are derived from empirical relationships that are evaluated based on regional or site-specific data The estimations are usually expressed as mean annual values.

Simple methods provide only rough estimates of sediment and pollutant loadings and have very limited predictive capability The empiricism contained in the models limits their transferability to other regions Because they often neglect seasonal variability, simple methods may not be adequate to model water quality problems for which shorter duration loadings are important They may be sufficient for problems such as nutrient loadings to and eutrophication of long-residence-time water bodies

Mid-Range Models The advantage of mid-range watershed-scale models is that they evaluate pollution sources and impacts over broad geographic scales and therefore can assist in defining target areas for pollution mitigation programs on a watershed basis Several mid-range models are designed to interface with geographic information systems (GIS), which greatly facilitate parameter estimation Greater reliance on site-specific data gives mid-range models a relatively broad range of regional applicability However, the use of simplifying assumptions limits the accuracy of their predictions to within about an order of magnitude (Dillaha, 1992) and restricts their analysis to relative comparisons

This class of model attempts a compromise between the empiricism of the simple methods and the complexity of detailed mechanistic models Mid-range models use a management-level approach to assessing pollutant sources and transport in watersheds by incorporating simplified relationships for the generation and transport of pollutants while still retaining responsiveness to management objectives and actions appropriate to watershed management planning (Clark et al , 1979) They are relatively simple and are intended to identify problem areas within large drainage basins or to make preliminary, qualitative evaluations of BMP alternatives (Dillaha, 1992)

Unlike the simple methods, which are restricted to predictions of annual or storm loads, mid-range tools can be used to assess the seasonal or inter-annual variability of nonpoint source pollutant loadings and to assess long-term water quality trends Also, they can be used to address land use patterns and landscape configurations in actual watersheds They are based primarily on empirical relationships and generalized sources of information. In addition, they typically require site-specific data and some calibration. Mid-range models are designed to estimate the importance of pollutant contributions from multiple land uses and many individual source areas in a watershed. Thus, they can be used to target important areas of pollution generation and identify areas best suited for controls on a watershed basis Moreover, the continuous simulation furnished by some of these models provides an analysis of the relative importance of sources for a range of storm events or conditions In an effort to reduce complexity and data requirements, these models often are written for specific applications For instance, mid-range models can be designed for application to agricultural, urban, or mixed watersheds Some mid-range models simplify the description of transport processes while emphasizing possible reductions available with controls, others simplify the description of control options and emphasize the changes in pollutant concentrations as they move through the watershed

Detailed Models. Detailed models best represent the current understanding of watershed processes affecting pollution generation Detailed models are best able to address problem causes rather than simply describe overall conditions If properly applied and calibrated, detailed models can provide relatively accurate predictions of variable flows and water quality at any point in a watershed. The additional precision they provide, however, comes at the expense of considerable time and resource expenditure

Detailed models use storm event or continuous simulation to predict flow and pollutant concentrations for a range of flow conditions The models are large and were not designed with emphasis on their potential use by the typical State or local planner Many of these models were developed for research into the fundamental land surface and instream processes influencing runoff and pollutant generation rather than to communicate information to decision-makers faced with planning watershed management (Biswas, 1975)

Detailed models incorporate the manner in which watershed processes change over time in a continuous fashion rather than relying on simplified terms for rates of change (Addiscott and Wagenet, 1985) They tend to require rate parameters for flow velocities and pollutant accumulation, settling, and decay instead of capacity terms The length of time steps is variable and depends on the stability of numerical solutions as well as the response time for the system (Nix, 1991). Algorithms in the detailed model more closely simulate the physical processes of infiltration, runoff, pollutant accumulation, instream effects, and groundwater/surface water interactions. The input and output of detailed models have greater spatial and temporal resolution Moreover, the manner in which physical characteristics and processes differ over space is incorporated within the governing equations (Nix, 1991) Linkage to biological modeling is possible due to the comprehensive nature of continuous simulation models In addition, detailed hydrologic simulations can be used to design controls

2. REVIEW OF SELECTED WATERSHED-SCALE MODELS

2.1 Review Methodology

A three-step process was used to review existing watershed-scale models

- Model identification In addition to information gained through user experience, the model identification process was based on a review of abstracts obtained from computer searches, available case studies in which a modeling approach was used to address nonpoint source pollution, and available published literature Receiving water quality models and models developed for field-size studies were not considered in this review

- Model acquisition The acquisition process was initiated by contacting model distributors, potential model users, other consultants, and model developers A list of models acquired and their corresponding distributor references is presented in the Appendix The collection of models with potential use in the TMDL process is ongoing

- Model documentation Each model was thoroughly reviewed with respect to its theoretical basis, range of applicability, and input requirements Additional references concerning model application were also collected and used in this step The results of this review were compiled in the form of fact sheets and are presented in the Appendix This review forms the primary basis for the following discussions

2.2 Overview of Watershed-Scale Models

During the last 20 years, numerous watershed and nonpoint source models have been developed Some of these models have been (and still are) used successfully by watershed and water quality managers Other models have had limited use or have been rapidly incorporated into larger systems prior to real world applications or testing This latter group of models is not addressed in this review In addition, watershed models have been continuously updated and improved in light of new developments in computing facilities Older versions of currently used models are also not included in the present compendium Many of the models reviewed were developed or sponsored by Federal or State agencies, however, a few simple and mid-range models were developed by universities or private companies

The U S EPA currently supports and distributes two complex watershed models the Hydrologic Simulation Program - FORTRAN (HSPF), for watersheds with multiple land use categories, and the Storm Water Management Model (SWMM), developed primarily for urban land areas The versatility of HSPF and SWMM for simulating a wide range of land uses and their continual upgrading make these models two of the most detailed and widely applied to watershed studies EPA also supports a simple screening procedure for assessing nonpoint loads This procedure (McElroy et al., 1976, Amy et al , 1974, Mills et al., 1985), a compilation of empirical relations and loading functions, can be applied using a hand-held calculator The procedure provides average annual estimates of loadings of toxic compounds in addition to those of conventional pollutants.

The U S. Department of Agriculture - Soil Conservation Service (USDA-SCS) has developed several relatively simple, well-documented models that may potentially be considered for TMDL development in rural and agricultural watersheds (e g , Agricultural Non-Point Source Pollution Model (AGNPS); Simulator for Water Resources in Rural Basin-Water Quality model (SWRRB or SWRRBQ), Erosion-Productivity Impact Calculator (EPIC), Groundwater Loading Effects of Agricultural Management Systems (GLEAMS), Chemicals, Runoff, Erosion from Agricultural Management Systems (CREAMS); and Nitrate Leaching and Economic Analysis Package (NLEAP)) These models were designed for various purposes ranging from the simple estimation of runoff and sediment loads from individual storm events to runoff routing, point and nonpoint source contributions, and continuous runoff and subsurface flow modeling on complex watersheds. Field-scale models, such as GLEAMS, CREAMS, NLEAP, and EPIC are designed for specific agricultural applications and may be used to target specific pollution sources, land uses, or land activities and to test the efficiency of control practices. The SWRRB model can be applied on a watershed basis for continuous simulation, but additional development and testing of model components for nutrient and pesticide transport is under way The AGNPS model is watershed-scale but is currently limited in application to design storms The USDA is upgrading AGNPS to include continuous simulation

The U S Army Corps of Engineers Hydraulic Engineering Center (HEC) developed a continuous urban simulation, including dry-weather sewer flows, in their Storage, Treatment, Overflow, Runoff Model (STORM) With support of HEC, STORM has been used extensively for planning purposes and for evaluating control strategies for combined sewer overflows The U S Geological Survey (USGS) has developed and applied the Distributed Routing Rainfall Runoff Model (DR3M-QUAL), calculating runoff and pollutant loads in several urban watersheds The USGS also developed a simple statistical method based on monitoring data from several gaging stations The U S Federal Highway Administration developed and used a simple pollutant loading model (FHWA) to assess water quality due to stormwater runoff from highways and to develop preliminary pollution control options

A number of models were developed at universities or other research institutions The Areal' Nonpoint Source Watershed Environment Response Simulation model (ANSWERS) was developed at the University of Georgia to predict the movement of sediment through relatively large agricultural watersheds The Source Loading and Management Model (SLAMM) was developed at the University of

Alabama for the purpose of evaluating urban management practices for sediment, nutrients, and other urban pollutants including toxics and oxygen-demanding substances The Generalized Watershed Loading Function (GWLF) model, a mid-range model, was developed at Cornell University The GWLF model considers runoff from rural and urban land uses and integrates pollution from both point sources and nonpoint sources Watershed is a simple nonpoint source model developed at the University of Wisconsin to assess the cost-effectiveness of stormwater control practices

Several State and local agencies have participated in the development of nonpoint source models Water Screen is a loading-function-based method developed by the Office of Planning and Zoning, Anne Arundel County, Annapolis, Maryland The Illinois State Water Survey developed a mid-range model (Auto-Q-Illudas or Auto-QI) for continuous simulation of pollutant loading from built-up areas The Washington Metropolitan Council of Governments developed a simplified approach, "the Simple Method," for estimating pollutant loads from urban land uses (Schueler, 1987) This approach relies on data from the National Urban Runoff Program (NURP) for default values Watershed Management Model (WMM) is under development for the Florida Department of Environmental Regulation to evaluate nonpoint source pollution loads and control strategies The Urban Catchment Model (P8-UCM), was developed for the Narragansett Bay Project The P8-UCM model predicts pollutant loading and transport of storm water runoff from urban watersheds

Other models developed by private companies include the Simplified Particle Transport Model (SIMPTM) and the Nonpoint Source Model for Analysis and Planning (NPSMAP) SIMPTM was developed by OTAK, Incorporated, to estimate pollutant loads from impervious areas and to evaluate the effectiveness of a number of urban stormwater practices The NPSMAP is a spreadsheet-based model designed to simulate stream segment load capacities (LCs), point source wasteload allocations (WLAs), and nonpoint source load allocations (LAs)

2.3 Model Descriptions

Several watershed-scale models have been selected as potential candidates for use in the TMDL development process and are included in this compendium A qualitative evaluation of each model in terms of its simulation capabilities, modeling performance, and ease of use was developed from available documentation and published applications to real-world case studies The results of this qualitative evaluation for the three categories of models are summarized in Tables 1, 2, and 3 These models differ in the type and the manner in which they describe the hydrologic and pollutant loss processes, the type of pollutant and pollution sources they address, the level of accuracy they provide, and the input data, personnel training, and resources and computing capabilities they require

Simple methods generally use simplistic and empirical relations to describe a limited number of hydrologic and pollution processes As can be seen from Table 1, these methods use large simulation time steps to provide long-term averages or

Table 1 Evaluation of Model Capabilities - Simple Models

Criteria		EPA Screening[1]	Simple Method[1]	Regression Method[1]	SLOSS-PHOSPH[2]	Water Screen	Watershed	FHWA	WMM
Land Uses	Urban	○	◐	◐	-	○	◐	○[3]	●
	Rural	◐	-	○	◐	◐	◐	○	●
	Point Sources	-	-	-	-	-	○	-	○
Time Scale	Annual	●	●	●	●		●	●	●
	Single Event	○	○	○	-	-	-	○	-
	Continuous	-	-	-	-	-	-	-	-
Hydrology	Runoff	-[4]	◐	-	-	-	-	○	○
	Baseflow	-	-	-	-	-	-	-	○
Pollutant Loading	Sediment	◐	◐	◐	◐	◐	◐	-	-
	Nutrients	◐	◐	◐	◐	◐	◐	◐	◐
	Others	◐	◐	◐	-	-	◐	◐	◐
Pollutant Routing	Transport	-	-	-	-	-	-	-	-
	Transformation	-	-	-	-	-	-	-	○
Model Output	Statistics	-	-	-	-	-	◐	○	○
	Graphics	-	-	-	-	-	◐	-	○
	Format Options	-	-	-	-	-	◐	-	○
Input Data	Requirements	○	○	○	○	○	○	○	○
	Calibration	-	-	-	○	○	◐	-	◐
	Default Data	●	●	◐	◐	○	○	◐	◐
	User Interface	-	-	-	-	○	◐	○	◐
BMPs	Evaluation	○	○	-	○	○	◐	◐	◐
	Design Criteria	-	-	-	-	-	-	-	-
Documentation		●	●	●	●	◐	●	●	◐

[1] Not a computer program
[2] Coupled with GIS
[3] Highway drainage basins
[4] Extended versions recommend use of SCS-curve number method for runoff estimation

● High ◐ Medium ○ Low - Not Available

Table 2 Evaluation of Model Capabilities - Mid-Range Models

Criteria		NPSMAP	GWLF	P8-UCM	SIMPTM	Auto-QI	AGNPS	SLAMM
Land Uses	Urban	●	●	●	●	●	-	●
	Rural	●	●	-	-	-	●	-
	Point Sources	◐	◐	●	-	-	●	●
Time Scale	Annual	-	-	-	-	-	-	-
	Single Event	○	-	●	-	-	●	-
	Continuous	●	●	-	-	●	-	●
Hydrology	Runoff	●	●	●	●	●	●	●
	Baseflow	○	●	-	○	○	-	○
Pollutant Loading	Sediment	-	●	-	●	●	●	●
	Nutrients	●	●	●	●	●	●	●
	Others	-	-	●	●	●	-	●
Pollutant Routing	Transport	○	○	○	○	◐	●	◐
	Transformation	-	-	-	-	-	-	-
Model Output	Statistics	◐	○	-	○	-	-	○
	Graphics	◐	◐	●	-	-	●	○
	Format Options	●	●	●	●	○	●	●
Input Data	Requirements	◐	◐	◐	◐	◐	◐	◐
	Calibration	○	○	○	○	◐	○	◐
	Default Data	●	●	◐	◐	○	◐	◐
	User Interface	●	●	●	◐	◐	◐	●
BMPs	Evaluation	○	○	●	◐	◐	◐	◐
	Design Criteria	-	-	●	○	◐	◐	○
Documentation		●	●	●	○	◐	●	◐

● High ◐ Medium ○ Low - Not Available

Table 3 Evaluation of Model Capabilities - Detailed Models

Criteria		STORM	ANSWERS	DR3M	SWRRBWQ	SWMM	HSPF
Land Uses	Urban	●	-	●	○	●	●
	Rural	-	●	-	●	○	◐
	Point Sources	●	-	●	●	●	●
Time Scale	Annual	-	-	-	-	-	-
	Single Event	○	●	○	○	●	●
	Continuous	●	-	●	●	●	●
Hydrology	Runoff	●	●	●	●	●	●
	Baseflow	○	-	○	●	●	●
Pollutant Loading	Sediment	●	●	●	●	●	●
	Nutrients	●	●	●	●	●	●
	Others	●	-	-	●	●	●
Pollutant Routing	Transport	-	◐	●	●	○	●
	Transformation	-	-	-	-	○	●
Model Output	Statistics	○	-	●	●	●	●
	Graphics	-	●	◐	◐	○	○
	Format Options	●	●	●	●	●	●
Input Data	Requirements	◐	●	●	◐	●	●
	Calibration	○	○	◐	◐	●	●
	Default Data	◐	○	●	●	◐	◐
	User Interface	-	-	◐	◐	-	-
BMPs	Evaluation	◐	◐	●	◐	●	●
	Design Criteria	◐	◐	◐	-	●	●
Documentation		●	◐	◐	●	●	●

● High ◐ Medium ○ Low - Not Available

annual estimates However, although they can easily be adopted to estimate seasonal or storm event loadings, their accuracy decreases since they cannot capture the large fluctuations of pollutant loading or concentration usually observed at smaller time steps In general, these methods rely on available default values and do not implicitly relate pollutant loads to hydrological processes Pollutant loads are determined from export coefficients (e g , Watershed) or as a function of the sediment yield (e g , EPA screening procedures, SLOSS-PHOSPH, Water Screen) The Simple Method, regression method, and FHWA methods are statistically based approaches developed from past monitoring information Their application is limited to the areas for which they were developed and to watersheds with similar land uses or activities

Mid-range models attempt to use smaller time steps in order to represent seasonal variability, therefore they require additional meteorologic data (e g , daily weather data for the GWLF, hourly rainfall for NPSMAP) They also attempt to relate pollutant loadings to hydrologic (e g , runoff) and erosion (e g , sediment yield) processes These models usually include adequate input-output features (e g , AGNPS, GWLF), making applications easier to process Several of these models (NPSMAP, Auto-QI) were developed in existing computing environments (e g , Lotus 1-2-3®) to make use of their built-in graphical and statistical capabilities It should be noted from Tables 1 and 2 that neither the simple nor the mid-range models consider degradation and transformation processes, and few incorporate adequate representation of pollutant transport within and from the watershed Although their applications may be limited to relative comparisons, however, they may provide water quality managers with necessary information for watershed-planning-level decisions

More detailed models, on the other hand, attempt to simulate the physical processes governing hydrologic and pollutant transport and transformation mechanisms Table 3 shows that these models use small time steps to allow for continuous and storm event simulations However, input data file preparation and calibration require professional training and adequate resources Some of these models (e g , STORM, SWMM, ANSWERS) were developed not only to support planning-level evaluations but also to provide design criteria for pollution control practices If appropriately applied, state-of-the-art models such as HSPF and SWMM can provide accurate estimations of pollutant loads and expected impacts on water quality However, their added accuracy may not always justify the amount of effort and resources they require Application of such detailed models is more cost-effective when used to address complex situations or objectives

A qualitative description of each model is presented in the following section to supplement the information reported in Tables 1, 2, and 3 For a more technical description, the reader is referred to the Appendix to this compendium

2.3.1 Simple Methods

EPA Screening Procedures The EPA Screening Procedures were developed by the EPA Environmental Research Laboratory in Athens, Georgia, (McElroy et al , 1976, Mills, 1985) to calculate pollutant loads from point and nonpoint sources, including atmospheric deposition, for preliminary assessment of water quality The procedures consist of loading functions and simple empirical expressions relating nonpoint pollutant loads to other readily available parameters Data required generally include information on land use/land cover, management practices, soils, and topography Although these procedures are not coded into a computer program, several computer-based models have adapted the loading function concept to predict pollutant loadings An advantage of this approach is the possibility of using readily available data as default values when site-specific information is lacking Application of these procedures requires minimum personnel training and practically no calibration. However, application to large, complex watersheds should be limited to pre-planning activities

The Simple Method. The Simple Method is an empirical approach developed for estimating pollutant export from urban development sites in the Washington, DC area (Schueler, 1987) It is used at the site-planning level to predict pollutant loadings under a variety of development scenarios. Its application is limited to small drainage areas of less than a square mile Pollutant concentrations of phosphorus, nitrogen, chemical oxygen demand, biological oxygen demand (BOD), and metals are calculated from flow-weighted concentration values for new suburban areas, older urban areas, central business districts, hardwood forests, and urban highways. The method relies on the NURP data for default values (US EPA, 1983) A graphical relationship is used to determine the event mean sediment concentration based on readily available information This method is not coded into a computer program but can be easily implemented with a hand-held calculator

USGS Regression Approach The regression approach developed by USGS researchers is based on a statistical description of historic records of storm runoff responses on a watershed level (Tasker and Driver, 1988) This method may be used for rough preliminary calculations of annual pollutant loads when data and time are limiting Simple regression equations were developed using available monitoring data of pollutant discharges at over 70 gaging stations in 20 States Separate equations are given for ten pollutants, including dissolved and total nutrients, chemical oxygen demand, and metals Input data include drainage area, percent imperviousness, mean annual rainfall, general land use pattern, and mean minimum monthly temperature Application of this method provides storm-mean pollutant loads and corresponding confidence intervals The use of this method as a planning tool at a regional or watershed level may require preliminary calibration and verification with additional, more recent monitoring data

Simplified Pollutant Yield Approach (SLOSS-PHOSPH) This method uses two simplified loading algorithms to evaluate soil erosion, sedimentation, and phosphorus transport from distributed watershed areas The SLOSS algorithm provides estimates of sediment yield, while the PHOSPH algorithm uses a loading function to evaluate the amount of sediment-bound phosphorus Application to watershed and subwatershed levels was developed by Tim et al (1991) based on an integrated approach coupling these algorithms with the Virginia Geographical Information System (VirGIS) The approach was applied to the Nomini Creek Watershed, Westmoreland County, Virginia, to target critical areas of nonpoint source pollution at the subwatershed level In this application, analysis was limited to phosphorus loading, however, other pollutants for which input data or default values are available can be modeled in a similar fashion The approach requires full-scale GIS capability and trained personnel

Water Screen Water Screen was developed by the Office of Planning and Zoning, Anne Arundel County, Annapolis, Maryland, for the Apple II microcomputer The program can be used at the planning level to estimate loadings of sediment, nitrogen, phosphorus, BOD, lead, and zinc from various land uses in a watershed This model uses a loading function approach similar to that developed in the EPA screening procedures (McElroy et al , 1976) and does not require meteorologic data since pollutant loads are computed from estimates of sediment yield Estimation of nitrogen loads considers both losses from surface soils and input from precipitation. This model was tested on the Church Creek watershed, south of Annapolis, Maryland (Bird and Conaway, 1985)

Watershed. Watershed is a spreadsheet model developed at the University of Wisconsin to calculate phosphorus loading from point sources, combined sewer overflows (CSOs), septic tanks, rural croplands, and other urban and rural sources The Watershed program can be used to evaluate the tradeoffs between control of point and nonpoint sources (Walker, Pickard, and Sonzogni, 1989) It uses an annual time step to calculate total pollution loads and to evaluate the cost-effectiveness of pollution control practices in term of cost per unit load reduction The program uses a series of worksheets to summarize watershed characteristics and to estimate pollutant loadings for uncontrolled and controlled conditions Because of the simple formulation describing the various pollutant loading processes, the model can be applied using available default values with minimum calibration effort Watershed was applied to study the tradeoffs between controlling point and nonpoint sources in the Delavan Lake watershed in Wisconsin

The Federal Highway Administration (FHWA) Model The Office of Engineering and Highway Operations has developed a simple statistical spreadsheet procedure to estimate pollutant loading and impacts to streams and lakes that receive highway stormwater runoff (Federal Highway Administration, 1990) The procedure uses several worksheets to tabulate site characteristics and other input parameters, as well as to calculate runoff volumes, pollutant loads, and the magnitude and frequency of occurrence of instream pollutant concentrations The FHWA model uses a set of default values for pollutant event-mean concentrations that depend on traffic volume and the rural or urban setting of the highway's pathway This method is used by the Federal Highway Administration to identify and quantify the constituents of highway runoff and their potential effects on receiving waters and to identify areas that may require controls

Watershed Management Model (WMM) The Watershed Management Model was developed for the Florida Department of

Environmental Regulation for watershed management planning and estimation of watershed pollutant loads (Camp, Dresser, and McKee, 1992). Pollutants simulated include nitrogen, phosphorus, lead, and zinc from point and nonpoint sources The model is implemented in the Lotus 1-2-3® spreadsheet environment and will thus calculate standard statistics and produce plots and bar charts of results Although it was developed to predict annual loadings, this model can be adapted to predict seasonal loads provided that seasonal event mean concentration data are available In the absence of site-specific information, the event concentration derived from the NURP surveys may be used as default values The model includes computational components for stream and lake water quality analysis using simple transport and transformation formulations based on travel time The WMM has been applied to several watersheds including the development of a master plan for Jacksonville, Florida, and the Part II estimation of watershed loadings for the NPDES permitting process It has also been applied in Norfolk County, Virginia; to a Watershed Management Plan for North Carolina, and to a wasteload allocation study for Lake Tohopekaliga, near Orlando, Florida.

2.3.2 Mid-Range Models

Nonpoint Pollution Source Model for Analysis and Planning (NPSMAP). NPSMAP is spreadsheet program developed to simulate nonpoint source runoff and nutrient loadings, in addition to point source discharges (Omicron Associates, 1990). Nonpoint source runoff simulations incorporate irrigation, evapotranspiration, and drainage to groundwater Point source discharge simulations include infiltration, overflows and bypasses, and changes in treatment plant performance NPSMAP can also evaluate surface water storage in reservoirs and wetlands, evaluate water uses, and perform preliminary water quality analyses The model can be used to evaluate user-specified alternative control strategies, and it simulates stream segment load capacities (LCs) in an attempt to develop point source wasteload allocations (WLAs) and nonpoint source load allocations (LAs) Probability distributions for runoff and nutrient loadings can be calculated by the model based on either single-event or continuous simulations The model can be applied in urban, agriculture, or complex watershed simulations The spreadsheet-based NPSMAP operates within the Lotus 1-2-3® programming environment and is capable of producing graphic output Although this model requires a minimum calibration effort, it requires moderate effort to prepare input data files The current version of the program considers only nutrient loading, sediment and other pollutants are not yet incorporated into the program The model is easily interfaced with GIS (ARC/INFO) to facilitate preparation of land use files The developers also plan to interface the model with remote sensing facilities for updated land use information NPSMAP has been applied to the Tualatin River basin for the Oregon Department of Environmental Quality

Generalized Watershed Loading Functions (GWLF) Model The GWLF model was developed at Cornell University to assess the point and nonpoint loadings of nitrogen and phosphorus from a relatively large, agricultural and urban watershed and to evaluate the effectiveness of certain land use management practices (Haith and Shoemaker, 1987) One advantage of this model is that it was written with the express purpose of requiring no calibration, making extensive use of default parameters. The GWLF model includes rainfall/runoff and erosion and sediment generation components, as well as total and dissolved nitrogen and phosphorus loadings The current version of this model does not account for loadings of toxics and metals, but with minimal effort improvements can be made to add this feature This model uses daily time steps and allows analysis of annual and seasonal time series The model also uses simple transport routing, based on the delivery ratio concept In addition, simulation results can be used to identify and rank pollution sources and evaluate basinwide management programs and land use changes The model also includes several reporting and graphical representations of simulation output to aid in interpretation of the results This model was successfully tested on a medium-size watershed in New York (Haith and Shoemaker, 1987) It is currently being updated to include an enhanced user interface with potential linking to available national databases for rapid and effective assessment of watershed point and nonpoint source pollution problems

Urban Catchment Model (P8-UCM) The P8-UCM program was developed for the Narragansett Bay Project to simulate the generation and transport of stormwater runoff pollutants in small urban catchments and to assess impacts of development on water quality, with minimum site-specific data It includes several routines for evaluating the expected removal efficiency for particular site plans, selecting or siting best management practices (BMPs) necessary to achieve a specified pollutant removal, and comparing the relative changes in pollutant loads as a watershed develops (Palmstrom and Walker, 1990) Default input parameters can be derived from NURP data and are available as a function of land use, land cover, and soil properties However, without calibration, the use of model results should be limited to relative comparisons Spreadsheet-like menus and on-line help documentation make extensive user interface possible On-screen graphical representations of output are developed for a better interpretation of simulation results The model also includes components for performing monthly or cumulative frequency distributions for flows and pollutant loadings

Simplified Particle Transport Model (SIMPTM) The Simplified Particle Transport Model was developed by OTAK, Inc to simulate runoff, sediment, and pollutant yield from urban watersheds and to determine the effectiveness of controls such as street sweeping (Sutherland, Green, and Jelen, 1990) Runoff volumes, durations, pollutant loadings, and event mean concentrations are reported for each rainfall event on a watershed and a subcatchment basis Included in the model results are standard statistics for average monthly and annual loadings SIMPTM is an event- or multiple-event-based model for simulation of urban nonpoint source loadings for six pollutants, including sediment, metals, nutrients, and chemical oxygen demand The model simulates the accumulation, washoff, and mechanical removal of pollutants contained in particulate matter that builds up on streets

SIMPTM was calibrated using the NURP data from Lake Hills basin in Bellevue, Washington NURP data from nearby Surrey Downs basin were used for testing SIMPTM The observed variability of runoff was greater than was predicted by the model, but the estimates were good considering the simplistic approach used for generating runoff SIMPTM was used for planning stormwater management for the area surrounding Reno, Nevada

Automated Q-ILLUDAS (AUTO-QI) AUTO-QI is a watershed model developed by the Illinois State Water Survey to perform continuous simulations of stormwater runoff from pervious and impervious urban lands (Terstriep et al , 1990) It also allows the examination of storm events or storm sequence impacts on receiving water Critical events are also identified by the model However, hourly weather input data are required Several pollutants, including nutrients, chemical oxygen demand, metals, and bacteria can be analyzed simultaneously This model also includes a component to evaluate the relative effectiveness of best management practices An updated version of Q-ILLUDAS, with an improved user interface and linkage to the Geographic Information System (ARC/INFO on PRIME computer), has been completed by the Illinois State Water Survey This interface is provided to generate the necessary input files relating to land use, soils, and control measures AUTO-QI was recently verified on the Boneyard Creek in Champaign, Illinois The model was also applied to the Greater Lake Calumet area to determine annual pollutant loadings to the Calumet and Little Rivers, south of Chicago

Agricultural Nonpoint Source Pollution Model (AGNPS) Developed by the USDA Agricultural Research Service, AGNPS addresses concerns related to the potential impacts of point and nonpoint source pollution on surface and groundwater quality (Young et al , 1989) It was designed to quantitatively estimate pollution loads from agricultural watersheds and to assess the relative effects of alternative management programs The model simulates surface water runoff along with nutrient and sediment constituents associated with agricultural nonpoint sources, and point sources such as feedlots, wastewater treatment plants, and stream bank or gully erosion The available version of AGNPS is storm-event based, however, the USDA will soon be releasing a continuous simulation version, ANNAGNPS The structure of the model consists of a square grid cell system to represent the spatial distribution of watershed properties This grid system allows the model to be connected to other software such as Geographical Information System (GIS) and Digital Elevation Models (DEM) This connectivity can facilitate the development of a number of the model's input parameters Two new terrain-enhanced versions of the model, AGNPS-C, a contour-based version, and AGNPS-G, a grid-based version, have been developed to automatically generate the grid network and the required topographic parameters (Panuska et al , 1991) The model also includes enhanced graphical representations of input and output information AGNPS has been extensively used by resource agencies in Minnesota and surrounding States It was also applied to develop cost-effective nonpoint pollution control alternatives in Idaho and Illinois and St Albans Bay, Vermont GIS was linked with AGNPS to model sediment loading to surface waters of the Wet Beaver Creek watershed of North-Central Arizona

Source Loading and Management Model (SLAMM) SLAMM was developed at the University of Alabama to assist in evaluating the effects of alternative control practices and development characteristics on urban runoff quality and quantity (Pitt, 1986) It evaluates only runoff characteristics at the source areas in the watershed and the discharge outfall, it does not directly evaluate receiving water responses However, output data from the model have been used in conjunction with other receiving water models to examine the ultimate effects of urban runoff The model performs continuous storm mass balances for both particulate and dissolved pollutant loadings, and computes runoff flow volume for different development and rain characteristics It is intended to be used as a planning-level tool and to provide rapid assessment of the effects of a number of urban stormwater control practices including detention basins, infiltration devices, porous pavement, street cleaning, grass swales, and roof runoff disconnections Proposed features to be added in an upcoming version of the model include cost estimates of stormwater control practices, graphical summaries, and baseflow and snowmelt predictions SLAMM was used in Wisconsin to evaluate the trade-offs between increased street sweeping, diversion of roof drains to pervious areas, and detention basins, as well as combinations of these practices The costs per unit of suspended solids removal was compared in order to rank the control options The model has also been used to evaluate pathogens from CSOs, for Madison, Wisconsin's stormwater permit program, and in Birmingham, Alabama and in Ottawa and Toronto, Canada

Sewer Overflow Model (SOM) SOM was developed by Limnotech as a hybridized version of the urban STORM and SWMM models It generates pollutant loadings from urban land uses and evaluates transport through interconnected sewer line networks SOM has been applied in six locations to study CSOs and stormwater pollution A 15-year continuous simulation was performed for Portland, Oregon, and options for controlling dissolved oxygen (DO) problems associated with large storm events in Richmond, Virginia were analyzed It also has been applied for evaluation of CSOs in Wayne County, Michigan, and South Bend, Indiana SOM can perform simulations of an event or a continuous series of events It is used to evaluate existing conditions as well as to perform planning-level analysis of controls

2.3.3 Detailed Models

Storage, Treatment, Overflow Runoff Model (STORM). STORM is a U S Army Corps of Engineers (COE) model developed for continuous simulation of runoff quantity and quality, including sediments and several conservative pollutants It also simulates combined sewer systems (Hydrologic Engineering Center, 1977) STORM has been widely used for planning and evaluation of the trade-off between treatment and storage control options for CSOs Long-term simulations of runoff quantity and quality lend themselves to the construction of duration-frequency diagrams These diagrams are useful in developing urban planning alternatives and designing structural control practices STORM was primarily designed for modeling stormwater runoff from urban areas. It requires relatively moderate to high calibration and input data STORM was initially developed for mainframe computer usage; however, several versions have been adapted by various individual consultants for use on microcomputers

Areal Nonpoint Source Watershed Environment Response Simulation Model (ANSWERS). ANSWERS is a comprehensive model developed at the University of Georgia to evaluate the effects of land use, management schemes, and conservation practices or structures on the quantity and quality of water from both agricultural and nonagricultural watersheds (Beasley, 1986) The distributed structure of this model allows for a better analysis of the spatial as well as temporal variability of pollution sources and loads It was initially developed on a storm event basis to enhance the physical description of erosion and sediment transport processes Data file preparation for the ANSWERS program is rather complex and requires mainframe capabilities, especially when dealing with large watersheds The output routines are quite flexible; results may be obtained in several tabular and graphical forms The program has been used to evaluate management practices for agricultural watersheds and construction sites in Indiana. It has been combined with extensive monitoring programs to evaluate the relative importance of point and nonpoint source contributions to Saginaw Bay. This application involved the computation of unit area loadings under different land use scenarios for evaluation of the trade-offs between LAs and WLAs Recent model revisions include improvments to the nutrient transport and transformation subroutines (Dillaha et al , 1988) Future improvements may include linkage of the grid-based system with GIS technology

Distributed Routing Rainfall Runoff Model (DR3M or DR3M-QUAL) The DR3M model, including a quality simulation component, is supported by the U S Geologic Survey (USGS) (Alley, 1986) This model was developed for the study of conventional pollutants in predominantly urban watersheds and includes components for sewer flow routing It can be used at the planning assessment level and as a design tool It is both a continuous and storm event-based simulator of nutrient and sediment loadings The model requires moderate to high calibration combined with a high level of personnel training It also requires mainframe computing capabilities Adequate input/output features are incorporated into the model to facilitate use and result interpretations Time series hydrographs and pollutographs can be presented in tabular or graphical form The USGS has used DR3M-QUAL for calculating urban runoff pollutographs in Southern Florida, Anchorage, and Fresno (Donigian and Huber, 1991)

Simulation for Water Resources in Rural Basins - Water Quality (SWRRB or SWRRBQ) The SWRRBQ model was adapted from the field-scale CREAMS model by USDA to simulate hydrologic, sedimentation, nutrient, and pesticide movement in large, complex rural watersheds (Arnold et al , 1989) SWRRBQ uses a daily time step to evaluate the effect of management decisions on water, sediment yields, and pollutant loadings The processes simulated within this model include surface runoff, percolation, irrigation return flow, evapotranspiration, transmission losses, pond and reservoir storage, sedimentation, and crop growth The model is useful for estimation of the order of magnitude of pollutant loadings from relatively small watersheds or watersheds with fairly uniform properties Input requirements are relatively high, and experienced personnel are required for successful simulations The National Oceanic and Atmospheric Administration (NOAA) is using SWRRBQ to evaluate pollutant loadings to coastal estuaries and embayments as part of its national Coastal Pollution Discharge Inventory The model has been run for all major estuaries on the east coast, west coast, and gulf coast for a wide range of pollutants (Donigian and Huber, 1991)

Storm Water Management Model (SWMM) SWMM is a comprehensive watershed-scale model developed by EPA (Huber and Dickinson, 1988) It was initially developed to address urban stormwater and assist in storm-event analysis and derivation of design criteria for structural control of urban stormwater pollution Recently, SWMM was upgraded to allow continuous simulation and application to complex watersheds and land uses SWMM can be used to model several types of pollutants provided that input data are available No user-enhanced interface is currently provided to assist in input data entry However a windows-based user interface is under development Recent versions of the model can be used for either continuous or storm event simulation with user-specified variable time steps The model is relatively data-intensive and requires special effort for validation and calibration Its application in detailed studies of complex watersheds may require a team effort and highly trained personnel. SWMM has been applied to address various urban water quantity and quality problems in many locations in the United States and other countries (Huber, 1989, Donigian and Huber, 1991) In addition to developing comprehensive watershed-scale planning, typical uses of SWMM include predicting CSOs, assessing the effectiveness of BMPs, providing input to short-time- increment dynamic receiving water quality models, and interpreting receiving water quality monitoring data (Donigian and Huber, 1991)

The Hydrological Simulation Program - FORTRAN (HSPF) HSPF is a comprehensive package developed by the U S EPA for simulating water quantity and quality for a wide range of organic and inorganic pollutants from agricultural watersheds (Barnwell and Johanson, 1981) The model uses continuous simulations of water balance and pollutant generation, transformation, and transport Time series of the runoff flow rate, sediment yield, and user-specified pollutant concentrations can be generated at any point in the watershed The model also includes in-stream quality components for nutrient fate and transport, BOD, DO, pH, phytoplankton, zooplankton, and benthic algae Statistical features are incorporated in the model to allow for frequency-duration analysis of specific output parameters Data requirements for HSPF are extensive, and calibration and verification are recommended The program is maintained on IBM microcomputers and DEC/VAX systems Because of its comprehensive nature, the HSPF model requires highly trained personnel It is recommended that its application to real case studies be carried out as a team effort The HSPF model has been extensively used for both screening-level and detailed analyses, including application to pesticide runoff testing (Lorber and Mulkey, 1982), aquatic fate and transport testing (Mulkey et al , 1986), and analysis of best management practices (Donigian et al , 1983)

3. OTHER MODELS

Many models have been developed to assess pollutant movement, transformation, and leaching in field-scale studies Like the watershed-scale models, these models range in detail from empirical relationships to physical and deterministic simulation models Many of these models provide for detailed analysis of the efficiencies of management practices and evaluation of alternative control options Although these models are not applicable to watershed or subwatershed analysis, they may be used in the TMDL process to assess more localized problems and to help develop appropriate nonpoint source pollution control strategies

The Occoquan Method The Occoquan Method was developed by the Northern Virginia Planning District Commission, Annandale, Virginia, to determine the design criteria required to achieve a given level of pollutant removal from development areas using structural practices The approach develops a site runoff coefficient as a function of imperviousness after development Overall pollutant removal efficiency for a given site is derived from the type of control practices used and the fraction of the total area controlled This method can be used for reviewing the adequacy of proposed control practices It was used in the development of BMPs for the Occoquan watershed (Northern Virginia Planning District Commission, 1987)

Water Resources Evaluation of Nonpoint Silvicultural Sources (WRENS) WRENS was originally developed by EPA to evaluate the effects of forest and silvicultural activities on water quality (USEPA, 1980) The method is compiled in a handbook that provides various quantitative techniques to estimate potential changes in stream flow, surface erosion and sediment yield, and water temperature The handbook also provides directions on how to compare alternative silvicultural management practices The basic formulations of this approach are similar to those developed in the EPA screening procedures

Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) CREAMS is the most detailed field-scale model available to evaluate agricultural runoff It was developed by the U S Department of Agriculture (USDA) to provide detailed information necessary for designing agricultural management systems (Knisel, 1980) CREAMS is a physically based, daily simulation model that estimates runoff, erosion/sediment transport, plant nutrients, and pesticide yield from field-size areas CREAMS can compare relative effects of different agricultural BMPs The model is data-intensive and requires highly trained personnel However, it may be applied with minimum calibration efforts A microcomputer version is currently available The hydrology, erosion and sediment, and pesticides components of CREAMS were used to develop Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) (Leonard et al , 1987) to simulate the vertical movement of pesticides and evaluate effects on groundwater quality

Pesticides Root Zone Model (PRZM) PRZM was developed by the EPA Environmental Research Laboratory, Athens, Georgia, to simulate chemical movement in the unsaturated zone within and below the plant root zone (Carsel et al , 1984) It considers pesticide application and accounts for plant uptake, decay, and transformation, and the dissolved, adsorbed, and vapor phase concentrations This model is linked to other models to simulate the transport and fate of pesticides and to assess the risk to drinking water wells. PRZM is a relatively comprehensive model requiring highly trained personnel However, it requires a moderate level of input data

The Water Erosion Prediction Project (WEPP). WEPP is a simulation model using daily time steps It is the result of a multi-agency effort to enhance researchers' ability to model erosion and sediment transport processes at field-scale and watershed levels (Laflan, Lane, and Foster, 1991). The model is currently under development and is intended to be used in soil erosion assessment and to provide necessary information for siting agricultural management practices on specific fields

Eutromod. Eutromod is a spreadsheet-based modeling procedure for eutrophication management developed at Duke University and distributed by the North American Lake Management Society (Reckhow, 1990). It is a watershed and lake model designed to estimate nutrient loadings, various trophic state parameters, and trihalomethane concentrations in lake water. The computation algorithms used in Eutromod were developed based on statistical relationships and a continuously stirred tank reactor model At present, the model is specific to watersheds in the southeastern United States with multiple land uses including rural and urban areas, feedlots, septic tanks, and discharges from wastewater treatment plants and construction sites Model results include the most likely predicted phosphorus and nitrogen loading for the watershed and for each land use category The model also determines the lake response to various pollution loading rates The spreadsheet capabilities of the model allow graphical representations of the results and data export to other spreadsheet systems for statistical analyses

Precipitation-Runoff Modeling System (PRMS) PRMS is a deterministic physical-process model developed by the USGS to evaluate the impacts of various combinations of precipitation, climate, and land use distribution on surface water runoff, sediment yield, and general watershed hydrology (Leavesley et al , 1983) It simulates watershed response to normal and extreme rainfall and snowmelt and determines changes in water balance relationships, flood peaks, and groundwater recharge It includes several capabilities for parameter optimization and sensitivity analysis The model divides the watershed into homogeneous hydrologic-response units (HRUs) and can be applied to both agricultural and urban land uses Input variables include descriptive data on the physiography, vegetation, soil, and hydrologic and climatic characteristics It is, however, designed to run with data retrieved directly from the USGS's National Water Data Storage and Retrieval (WATSTORE) system The modular system approach provides an adaptable modeling system for both management and research applications PRMS was initially developed for use on mainframe computers New model components proposed by the USGS as future additions to PRMS include water-quality routines and expanded saturated-unsaturated flow and groundwater flow components

The Unified Transport Model for Toxic Materials (UTM-TOX). UTM-TOX was developed by the Oak Ridge National Laboratory for the analysis of hydrologic, atmospheric, and sediment transport of pesticides and toxic substances (Patterson et al , 1983) This model consists of a multi-media simulation approach Considering a chemical release to the atmosphere from a given source (e g , stack, area, or line source), the model uses mass balance formulations to compute chemical fluxes from the source through the atmosphere, deposition on watersheds, transport in surface runoff and percolation through the soil profile, and transport in sediment and streamflow The model generates summary tables and plots of the average monthly and annual chemical concentrations in the various media It also considers biotic processes and computes chemical accumulation in stems, leaves, and fruits of impacted vegetation Limited applications of this model were reported in the literature due primarily to the complex nature of the model and the lack of user support (Donigian and Huber, 1991)

Exposure Analysis Modeling System (EXAMS) EXAMS was developed for the USEPA to provide rapid evaluations of the behavior of synthetic organic chemicals in aquatic systems (Burns and Cline, 1985) The initial version of EXAMS computes the long term results of continual, steady discharges of single chemicals into typical aquatic systems The new version includes updated routines which consider the seasonal variations of transport and transformation kinetics and computes the fate and transport of products resulting from transforation reactions The updated version also includes capabilities for flexible timing and durations of chemical loadings. The model requires laboratory information on the reactivity and transformation of chemicals as well as state variables describing the transport mechanisms and physical/chemical properties of the receiving water This model is widely used for exposure analysis and for deriving basic information necessary to perform health and ecological risk assessments

The Water quality Analysis Simulation Program (WASP4) WASP4 is a detailed receiving water quality model supported by the U S EPA (USEPA, 1988) It allows users to interpret and predict water quality responses to natural phenomena and man-made stresses for various pollution management decisions WASP4 is a dynamic compartment modeling program for aquatic systems, including both the water column and the underlying benthos The model includes the time-varying processes of advection, dispersion, point and nonpoint mass loading, and boundary exchanges WASP4 may be applied in two modes (1) EUTROWASP for nutrient and eutrophication analyses and (2) TOXIWASP for analysis of toxic pollutants and metals The flexibility of WASP4 is unique in that it permits the modeler to structure one, two, or three dimensional model applications to rivers, lakes, estuaries, or open coastal areas The model's computer code is structured to permit easy development of new kinetic or reactive subroutines without having to rewrite large sections of computer code The main advantage to using WASP4 is the ability to more realistically portray the relative spatial influence of each major pollutant source on the receiving water as well as a more accurate representation of the transport/ water quality kinetics phenomena (i e mixing and diurnal process) It may also be useful to assist in designing long term monitoring programs for receiving waters The model has been successfully applied to a wide range of estuary water bodies such as the Peconic Bay, Long Island, and the Bird River estuary, Maryland

Enhanced Stream Water Quality Model (QUAL2E). QUAL2E is an U S EPA supported model. It is a one dimensional (longitudinal water quality model) that assumes steady state flow but allows simulation of diurnal variations in temperature or algal photosynthesis and respiration. QUAL2E simulates a series of nonuniform segments that make up a river reach and incorporates the effects of withdrawals, branches, and tributaries Water quality parameters simulated include conservative substances, temperature, bacteria, BOD, DO, ammonia, nitrate, nitrate and organic nitrogen, phosphate and organic phosphorus, and algae QUAL2E is widely used for stream waste load allocations and discharge permit determinations in the United States and other countries (USEPA, 1992a)

Simplified Method Program - Toxics (SMPTOX) SMPTOX is an USEPA supported model It was developed to provide a user-friendly microcomputer program for performing screening level modeling of toxic chemical concentrations resulting from discharges from POTWs into streams and rivers It provides a simplified technique for performing load allocation for dissolved oxygen/ammonia/CBOD Because of its simplistic approach, several versions of SMPTOX are currently available (USEPA, 1992b) The program contains a full screen editor to facilitate the entry and modification of input data as well as high resolution graphics to present model results

4. MODEL SELECTION

Watershed models are becoming more and more integrated at various levels of water quality analysis At the same time, selecting the model that best matches the project or objective in hand is becoming difficult as more models are being developed The watershed models presented in the previous section cover a wide range of functions and can be applied, either directly or with minimum modification, to the majority of planning problems associated with point and nonpoint source pollution Selection of a watershed or water quality model may be considered an important decision process, not only because of the time and resources a modeling effort involves, but also because of the wide variety and amount of information a water quality project may require

4.1 Model Characteristics

In addition to information presented in the previous sections of this compendium, relevant characteristics generally associated with model selection for specific applications are presented in this section Tables 4, 5, and 6 present the basic simulation functions used in each model to generate pollutant loadings Most watershed models include three components a hydrology component, which estimates the quantity of runoff and streamflow generated from the watershed or subwatersheds, an erosion and sediment component, which derives the amount of sediment delivered to a receiving water body, and a quality component, which computes the pollutant loadings Tables 4-6 also present the type of pollutant handled by each model and the corresponding computation time steps

As shown in Tables 4-6, most models are based on similar mathematical formulations The curve number equation (CNE) developed by the USDA-SCS is widely used for simulating runoff and stream flows (e g , NPSMAP, GWLF, P8-UCM, AGNPS, STORM, SWRRBQ), and the Universal Soil Loss Equation (USLE) is commonly used for determining erosion and sediment yield from rural areas or watersheds (e g , EPA screening procedures, Water Screen, Watershed, SLOSS-PHOSPH, GWLF, AGNPS, STORM, SWRRBQ) Pollutant loadings from rural areas are often calculated based on loading functions or potency factors (e g , EPA screening procedures, Water Screen, AGNPS, SWRRBQ, HSPF) For urban areas, unit area loading rates (e g , GWLF) or build-up and washoff functions (e g , STORM, SWMM) are widely used The advantage of the CNE- and USLE-based models is that detailed default parameters are available for a wide variety of soil conditions and agricultural management techniques The differences among models using similar simulation functions reside in the degree of spatial discretization they use, the number

Table 4. A Descriptive List of Model Components - Simple Methods

Model	Main Land Use	Hydrology	Erosion/ Sediment	Pollutant Load	Pollutants	Time Scale
EPA Screening Procedures	Mixed watershed	N/A	USLE-MUSLE	Loading functions, potency factors	Wide range[1]	Mean annual
The Simple Method	Urban	Runoff coefficient	N/A	Mean concentration	NURP data TSS, P, metals, O&G	Variable (annual, monthly, event)
Water Screen	Mixed watershed	N/A	USLE	Loading functions, potency factors	N, P, organics	Mean annual
Watershed	Mixed watershed	N/A	USLE	Unit area loadings	Wide range[1]	Annual
FHWA	Highways	Runoff coefficient, observed data	N/A	Median concentration	TSS, N, P Organics, metals	Storm event
WMM	Mixed watershed	Runoff coefficient	N/A	Event mean concentration	N, P, lead, zinc	Annual
SLOSS/PHOSPH	Rural	N/A	USLE	Loading functions	P	Annual
Regression Method	Urban	N/A	N/A	Regression equations	TSS, N, P, COD, metals	Storm event

[1]Depends on available pollutant parameters and default data

N Nitrogen
O+G Oil and gas
P Phosphorus
TSS Total suspended solids
COD Chemical oxygen demand

Table 5 A Descriptive List of Model Components - Mid-Range Models

Model	Main Land Use	Hydrology	Erosion/ Sediment	Pollutant Load	Pollutants	Time Scale
NPSMAP	Mixed watershed	SCS curve number	N/A	Runoff concentration	N, P	Continuous
GWLF	Mixed watershed	SCS curve number	Modified USLE	Unit loading rates	N, P	Continuous
P8-UCM	Urban	SCS curve number -modified TR 20	N/A	Nonlinear accumulation	TSS, N, P, metals	Storm sequence
SIMPTM	Urban	Trapezoidal hyetograph	Modified Yalin equation	Nonlinear accumulation	Wide Range[1]	Storm sequence
Auto-QI	Urban	Water balance	N/A	Accumulation and washoff	Wide Range[1]	Storm event, Continuous
AGNPS	Agriculture	SCS curve number	Modified USLE	Potency factors	N, P	Storm event
SLAMM	Urban watershed	Small storm-based coefficient	N/A	Nonlinear accumulation and washoff	N, P, COD bacteria, metals	Continuous

[1]Depends on available pollutant parameters and default values

N Nitrogen
O+G Oil and gas
P Phosphorus
TSS Total suspended solids
COD Chemical oxygen demand

Table 6. A Descriptive List of Model Components - Detailed Models

Model	Main Land Use	Hydrology	Erosion/ Sediment	Pollutant Load	Pollutants	Time Scale
ANSWERS	Agriculture	Distributed storage model	Detachment transport equations	Potency factors (correlation with sediment)	N/A	Storm event
SWMM	Urban	Nonlinear reservoir	Modified USLE	Buildup/washoff functions	Wide range[1]	Storm event, continuous
HSPF	Mixed watershed	Water balance of land surface and soil processes	Detachment/ washoff equations	Loading/washoff functions and subsurface concentrations	Wide range[1]	Storm event, Continuous
STORM	Urban	Runoff coefficient - SCS curve numbers - Unit hydrograph	USLE	Buildup/washoff functions	P, N, OD, metals	Continuous
SWRRB	Agriculture	SCS curve number	Modified USLE	Loading functions	N, P, OD, metals, bacteria	Continuous
DR3M	Urban	Surface storage balance kinematic wave method	Related to runoff volume and peak	Buildup/washoff functions	TSS, N, P, organics, metals	Continuous

[1]Depends on available pollutant parameters and default values

N Nitrogen
O+G Oil and gas
P Phosphorus
TSS Total suspended solids
COD Chemical oxygen demand

of processes for which they account, and the computational time steps they use

Many of the simple methods do not take hydrologic processes into account when simulating pollutant loads When dealing with urbanized areas, simple methods usually generate runoff based on empirical or statistical relationships between runoff coefficients and the degree of imperviousness (e g , the Simple Method, FHWA, and WMM) It is, however, difficult to extrapolate such relationships to rural and agricultural areas

Detailed models use more complex formulations for simulating runoff and sediment yield The hydrology component generally involves a set of deterministic equations to represent the elements of the water balance equation (e g , infiltration, evapotranspiration, groundwater recharge and/or seepage, depression storage) These models also use a physical description of the erosion and sediment yield mechanisms (e g , soil detachment, transport, and deposition) Predictions of pollutant washoff are usually made based on exponential decay functions (e g , SWMM) with hourly time steps Default values for parameters are pollutant- and site-specific and therefore may not be readily available, making calibration difficult and time-consuming In most cases, additional laboratory testing and field measurement may be required

The type and amount of input data required for operation, calibration, and verification of the model and the output results should be considered in the model selection process Depending on the type of formulations the model uses, input data may range from simple watershed characteristics to hourly meteorological parameters, pollutant transformation kinetic coefficients, and field monitoring data Tables 7, 8, and 9 present a brief summary of input and output information for each of the models reviewed Novotny and Chesters (1981) have developed three sets of input parameters that may be required for a typical modeling application (Table 10) Interpretation of the type and amount of data required, along with information contained in the preceding tables, may be used to evaluate the time and resources required to apply a given model for a given situation or project For a detailed listing of input requirements, please refer directly to the model documentation

Watershed models are usually developed to target a specific setting, characterized primarily by land use or land activity Few models are developed to evaluate watersheds with mixed land uses Among the detailed models, HSPF appears to be the most versatile for watersheds with complex land use/land cover SWMM, STORM, and DR3M-QUAL are designed primarily for urban areas, while ANSWERS and SWRRB are primarily agricultural models Among the mid-range models, NPSMAP and GWLF are the two models that account for both rural and agricultural watersheds The GWLF model offers the possibility of generating long-term time series of pollutant loadings at various time steps, allowing analysis of seasonal and inter-annual variabilities GWLF also allows evaluation of watershed response to changes in land use patterns and point and nonpoint source loadings Urban models such as P8-UCM, SIMPTM, and SLAMM were mainly designed for evaluating management practices to control urban stormwater runoff Simple methods use

Table 7. Input and Output Data - Simple Methods

Models	Main Input Data	Output Information
EPA Screening Procedures	Watershed and land use data Loading factors (default values)	Mean annual sediment and pollutant loads
The Simple Method	Annual rainfall data Land use and imperviousness data Pollutant mean concentration BMPs removal efficiencies	Runoff volume and pollutant concentration/load, storm or annual
Regression	Mean annual rainfall Mean minimum January temperature Drainage areas and land use Percent imperviousness	Mean annual storm event load and confidence interval
SLOSS/PHOSPH	Rainfall erosivity factor Soil, crop, topography, and land use data	Mean annual loads of sediment and phosphorus
Water Screen	Rainfall erosivity factor Watershed and land use data Loading factors (default values)	Mean annual sediment and pollutant loads
Watershed	Rainfall erosivity factor Land use and soil parameters Unit loading rates BMP cost information	Mean annual pollutant loads BMP cost-effectiveness
FHWA	Site and receiving water data Flow and storm event concentrations	Statistics on storm runoff and concentrations Impacts on receiving water
WMM	Land use and soil data Annual precipitation and evaporation Inputs from baseflow and precipitation Event mean concentrations in runoff Reservoir, lake or stream hydraulic characteristics Removal efficiencies of proposed BMPs	Annual urban and rural pollutant loads from point and nonpoint sources, including septic tanks Load reductions from combined effects of multiple BMPs In-lake nutrient concentrations as related to trophic state, also concentrations of metals

Table 8. Input and Output Data - Mid-Range Models

Models	Main Input Data	Output Information
NPSMAP	Meteorologic and hydrologic data, hourly or daily maximum one year Watershed and channel parameters Point sources and pollutant parameters (e.g , decay)	Runoff and nutrient loadings Pollution load allocations
GWLF	Meteorologic and hydrologic data, daily Land use and soil data parameters Nutrient loading rates	Monthly and annual time series of runoff, sediment, and nutrients
P8-UCM	Meteorologic and hydrologic data, hourly storm or storm sequence Land use and soil parameters BMP information	Daily runoff and pollutant loads BMP removal efficiencies
SIMPTM	Rainfall event statistics Watershed parameters Accumulation and washoff rates (default values)	Storm runoff volume and hydrograph characteristics TSS/sediment and pollutant washoff
Auto-QI	Hourly/daily rainfall Watershed and land use data BMP removal rates	Continuous or storm event simulation of runoff and selected pollutants
AGNPS	Watershed, land use, management, and soil data Rainfall data, topography BMP removal data	Storm runoff volume and peak flow Sediment, nutrient, and COD concentrations
SLAMM	Hourly rainfall data Pollution source characteristics, areas, soil type, imperviousness, and traffic Structure characteristics	Pollutant load by source area BMP evaluation and cost estimates

Table 9. Input and Output Data - Detailed Models

Models	Main Input Data	Output Information
STORM	Hourly rainfall data Buildup and washoff parameters Runoff coefficient and soil type	Event-based runoff and pollutant loads Storage and treatment utilization and number of overflows Hourly hydrographs and pollutographs
ANSWERS	Hourly rainfall data Watershed, land use, and soil data BMP design data	Predicts storm runoff (volume and peak flow), Sediment detachment and transport Analysis of relative effectiveness of agricultural BMPs
DR3M	Meteorologic and hydrologic data Watershed characteristics related to runoff Channel dimensions and kinematic wave parameters Characteristics of storage basins Buildup and washoff coefficients	Continuous series of runoff and pollutant yield at any location in the drainage system. Summaries for storm events Hydrographs and pollutographs
SWRRB	Meteorologic and hydrologic data Watershed and receiving waterbody parameters Land use and soil data Ponds and reservoir data	Continuous water and sediment yield Peak discharge Water quality concentrations and loads
SWMM	Meteorologic and hydrologic data Land use distribution and characteristics Accumulation and washoff parameters Decay coefficients	Continuous and event-based runoff and pollutant loads Transport through streams and reservoirs Analysis of control strategies
HSPF	Meteorologic and hydrologic data Land use distribution and characteristics Loading factors and washoff parameters Receiving water characteristics Decay coefficients	Time series for runoff and pollutant loadings Analysis of impacts on receiving water Analysis of controls

Table 10. Input Data Needs for Watershed Models (after Novotny and Chesters, 1981)

1	**System Parameters** Watershed size Subdivision of the watershed into homogenous subareas Imperviousness of each subarea Slopes Fraction of impervious areas directly connected to a channel Maximum surface storage (depression plus interception storage) Soil characteristics including texture, permeability, erodibility, and composition Crop and vegetative cover Curb density or street gutter length Sewer system or natural drainage characteristics
2	**State Variables** Ambient temperature Reaction rate coefficients Adsorption/desorption coefficients Growth stage of crops Daily accumulation rates of litter Traffic density and speed Potency factors for pollutants (pollutant strength on sediment) Solar radiation (for some models)
3	**Input Variables** Precipitation Atmospheric fallout Evaporation rates

generic empirical relationships that can be used in both rural and urban settings provided site-specific or default values are available.

Model applications may be classified as screening, intermediate, or detailed depending on the focus and objectives of the application. Simple methods are most frequently used for screening applications, however, mid-range and detailed models may allow for a wider range of applications Screening applications are generally performed at the preplanning level, with specific objectives such as comparisons of the relative contribution of point and nonpoint sources using a relatively limited set of available information Screening analyses may consider a broad range of land use types and sources and may be performed at various stages of project development (e g , planning, evaluation of alternatives, preliminary design) At the planning level, screening applications may be directed toward scoping the project objective and identifying general areas where controls or additional sampling may be required.

Intermediate applications provide a more detailed description of the geographic variables contributing to nonpoint pollution, in addition to consideration of multiple point sources. Intermediate applications may assist in identifying specific point and nonpoint source activities and in preliminary selection of pollution control options incorporating a higher degree of spatial variation within land uses

As it becomes necessary to accurately distinguish differences in pollutant characteristics from multiple source areas, pollutant behavior is considered in more detail and a more mechanistic description of pollutant generation, transformation, and removal by various control practices is required Detailed applications are, therefore, necessary to provide either storm-based or continuous simulation of water and water quality processes and to assist in developing design criteria for achieving project objectives

The potential range of applications of watershed models in planning, evaluation of management measures, and analysis of impacts on the quality of receiving waters is illustrated in Tables 11, 12, and 13 The tables show that the majority of the models may be used for screening-level applications The simple methods in particular provide only an order-of-magnitude estimate on an annual basis and therefore are limited to screening applications at the planning level Some of the mid-range models (e g , GWLF, NPSMAP, and AGNPS) incorporate point and nonpoint source pollution routines and are also good candidates for screening activities SLAMM, P8-UCM, and SIMPTM are primarily urban runoff models, and their application to evaluation of urban stormwater control practices and strategies may be useful at an intermediate level SWMM, HSPF, DR3M, STORM, and SWRRB stand out from the others as models capable of providing a detailed indication of the contribution of pollutants from various point and nonpoint sources Their simulation capabilities allow for evaluation of control strategies and development of design criteria

Application of detailed models such as HSPF and SWMM for screening purposes, using estimated default values for a number of parameters, may reduce time and input requirements However, representative default values for many of the detailed models are difficult to obtain In addition, their accuracy as screening tools may be jeopardized by replacing mechanistic equations with their simplified forms and including inappropriate default values Urban stormwater runoff models, such as SWMM, HSPF, SLAMM, P8-UCM, and DR3M-QUAL, are capable of providing design criteria for a number of structural practices Models with such capabilities, however, are data-intensive and require trained professionals to operate the model, select appropriate default values, and interpret the results

4.2 Model Calibration and Verification

The results of watershed simulations are more meaningful when they are accompanied by some sort of confirmatory analysis The capability of any model to accurately depict water quality conditions is directly related to the accuracy of input data and the level of expertise required to operate the model It is also largely dependent on the amount of data available Detailed models lacking the required calibration and verification data are limited in accuracy.

Table 11 Range of Application of Watershed Models - Simple Methods

Simple Methods	Watershed Analysis			Control Analysis		Receiving Water Quality
	Screening	Intermediate	Detailed	Planning	Design	
EPA Screening	●	-	-	-	-	○
The Simple Method	●	-	-	○	-	-
Regression	●	-	-	-	-	-
SLOSS/PHOSPH	○	-	-	-	-	-
Water Screen	●	-	-	-	-	-
Watershed	●	-	-	○	-	-
FWHA	●	-	-	○	-	○
WMM	●	○	-	◐	-	◐

● High ◐ Medium ○ Low - Not Available

Table 12 Range of Application of Watershed Models - Mid-Range Models

Mid-Range Methods	Watershed Analysis			Control Analysis		Receiving Water Quality
	Screening	Intermediate	Detailed	Planning	Design	
NPSMAP	●	○	○	◐	-	○
GWLF	●	◐	○	-	-	-
P8-UCM	●	◐	◐	○	●	-
SIMPTM	○	◐	◐	◐	○	-
Auto-QI	●	●	○	◐	○	○
AGNPS	●	●	○	●	○	○
SLAMM	●	◐	○	●	○	○

● High ◐ Medium ○ Low - Not Available

Table 13. Range of Application of Watershed Models - Detailed Models

Detailed Methods	Watershed Analysis			Control Analysis		Receiving Water Quality
	Screening	Intermediate	Detailed	Planning	Design	
STORM	●	●	○	●	○	○
ANSWERS	●	●	◐	●	○	○
SWRRBQ	◐	●	●	●	◐	◐
DR3M-Q	◐	●	●	●	◐	◐
SWMM	◐	●	●	●	◐	-
HSPF	◐	●	●	●	◐	●

● High ◐ Medium ○ Low - Not Available

Calibration involves minimization of deviation between measured field conditions and model output by adjusting parameters of the model (Jewell et al , 1978) Data required for this step are a set of known input values along with corresponding field observation results The results of the sensitivity analysis provide information as to which parameters have the greatest effect on output For the best results, CSO models should be calibrated during storm events as opposed to dry flow periods (Water Pollution Control Federation, 1989)

Verification involves the use of a second set of independent information to check the model calibration The data used for verification should consist of field measurements of the same type as the data output from the model Specific features such as mean values, variability, extreme values, or all predicted values may be of interest to the modeler and require testing (Reckhow and Chapra, 1983) Models are tested based on the levels of their predictions, whether descriptive or predictive More accuracy is required of a model designed for absolute versus relative predictions If the model is calibrated properly, the model predictions will be acceptably close to the field observations

Observed data for model calibration and verification may, in many cases, be insufficient or unavailable Model selection must be based on an assessment of the available data Screening-level applications may be possible with limited input data As noted by Donigian and Rao (1988), most models are more accurate when applied in a relative rather than an absolute manner Model output data concerning the relative contribution of a watershed to overall pollutant loads is more reliable than an absolute prediction of the impacts of one control alternative viewed alone When examining model output from watershed-pollution sources, it is important to note three factors that may influence the model output and produce unreasonable data First, suspect data may result from calibration or verification data that are insufficient or inappropriately applied Second, any given model, including detailed models, may not represent enough detail to adequately describe existing conditions and generate reliable output Finally, modelers should remember that all models have limitations and the selected model may not be capable of simulating desired conditions Model results must therefore be interpreted within the limitations of their testing and their range of application Inadequate model calibration and verification can result in spurious model results, particularly when used for absolute predictions Data limitations may require that model results be used only for relative comparisons

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APPENDIX

WATERSHED-SCALE MODEL - FACT SHEETS

EPA Screening Procedures

1 Distributor

Center for Exposure Assessment Modeling
U S Environmental Protection Agency
Environmental Research Laboratory
Athens, Georgia 30613
(404) 546-3123

2 Type of Modeling:

- Not a computer program, consists of a series of equations/techniques
- Pollutant loadings
- Multiple diffuse source
- Annual time steps, but may be used for storm events
- Screening application

3. Model Components

- Loading functions for various land uses/land activities
- Irrigation return flows
- Atmospheric inputs
- Pesticides in runoff and sediment

4 Method/Techniques

Loading functions estimate pollutant loadings for screening applications and comparison purposes A generic loading function is of the following form

$$L_{ie} = a \cdot X_e \cdot C_{si} \cdot Er_i$$

where

L_{ei} = pollutant load in sediment
X_e = sediment yield
C_{si} = concentration of pollutant i in soil
Er_i = enrichment factor for pollutant i
a = dimensional constant

Additional pollutant load from rainfall may be accounted for using the following formulation

$$L_{ri} = A \cdot \frac{Q_r}{Q_p} \cdot C_n \cdot b$$

where

L_{ri} = pollutant load to streams from rainfall
Q_r = overland flow
Q_p = rainfall amount
C_{ri} = concentration of pollutant in rainfall
b = attenuation factor

Runoff can be estimated from the SCS curve number equation and sediment yield can be calculated from the USLE Soil concentration and enrichment factors can be determined from field measurement or from available default values Several variations of these forms of loading function can be used to represent other pollutant and pollution sources

5 Applications·

Loading functions have been incorporated into several hydrologic models to estimate pollutant loadings They are also widely used for screening purposes using desktop calculators They can be used to evaluate atmospheric inputs, urban, and agricultural sources including irrigation return flows, mining activities, and feedlots

6. Number of Pollutants:

Nitrogen, phosphorus, sediment, heavy metals, pesticides, organics, salinity

7. Limitations:

- Accuracy is limited when default parameters are substituted for site specific data
- Neglects seasonal variation
- Can be adapted to predict event or seasonal loadings
- Does not evaluate control practices except through assumption of a constant removal rate or changes in USLE parameters
- Application can be tedious and time-consuming for basins with complex multiple land uses and/or pollution sources

8. Experience.

EPA Screening Procedures have been applied (Donigian and Huber, 1991) to the Sandusky River in Northern Ohio and the Patuxent, Ware, Chester, and Occoquan basins in the Chesapeake Bay region (Davis et al., 1981, Dean et al , 1981).

9. Updating Version:

N/A

10. Input Data Requirements:

- Pollutant concentrations in soils
- Enrichment ratios
- Nutrient concentrations in precipitation
- Parameters in the USLE
- Land use data

11 Simulation Output.

- Annual pollutant loads (may be adopted for seasonal or storm events)
- Nitrogen inputs to groundwater
- Salinity in irrigation return flows

12. References Available.

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The Simple Method

1 Distributor:

Metropolitan Washington Council of Governments (MW-COG)
777 North Capitol St , Suite 300
Washington, DC 20002
(202) 962-3200

2 Type of Modeling:

- Not a computer program
- Pollutant concentration from urban drainage areas
- Diffuse source
- Storm-based computations
- Screening application

3. Model Components·

- Pollutant export in storm runoff
- Sediment event mean concentration estimates
- Threshold exceedance frequencies

4 Method/Techniques:

The Simple Method uses the following expression as its governing equation

$$L_l = P \cdot P_j \cdot R_v \cdot C \cdot A \cdot \frac{2.72}{12}$$

where
L_l =pollutant loading (lbs/year)
P =average annual rainfall (inches)
P_j =unitless correction factor to account for storms that produce no runoff
R_v =runoff coefficient (dimensionless)
C =flow-weighted mean pollutant concentration (mg/L)
A =area of development (acres)

Runoff is estimated using runoff coefficients for the fraction of rainfall converted to runoff The portion of storms that do not produce runoff are accounted for by a correction factor determined based on analyis of site specific or regional precipitation pattern (p = 0 9 for Washington, DC area). Runoff coefficients are determined based on the following equation

$$R_v = 0.05 + 0.009 \cdot PI$$

where
PI = percent imperviousness

Pollutant concentrations in runoff depend on the land use/land activity and can be obtained from sampling programs such as the NURP program Sediment event mean concentrations are calculated as a function of the surface area of the drainage basin It is assumed that the channels in urban watersheds are a major source of sediment and thus larger watersheds will have higher event mean concentrations Factors such as the channel stability, storage, and stream velocity are taken into account in the event mean concentration determination

5. Applications.

- Estimate increased pollutant loading from an uncontrolled development site
- Estimate expected extreme concentration that occurs over a specified interval of time

6. Number of Pollutants

Phosphorus, nitrogen, COD, BOD, metals, including zinc, copper, and lead

7. Limitations:

- Limited to watersheds where data are available or must assume national NURP values
- It is intended for recently stabilized suburban watersheds
- It is limited to small watersheds (less than 1 square mile)
- Application limited to relative comparisons

8. Experience:

The Simple Method is used to evaluate development plans in the metropolitan Washington, D.C area

9. Updating Version:

N/A

10. Input Data Requirements:

- Characteristics of pollution sources
- Flow and concentrations of point sources
- Areas served by urban land uses such as storm sewers, combined sewers, and unsewered areas along with their corresponding unit area loads for the pollutant of concern
- Areas and unit area loads for grass and woodland areas
- Parameters for the USLE for croplands
- Pollutant delivery ratios and pollutant reduction efficiency ratio
- Treatment schemes and associated costs

11 Simulation Output:

- Total annual loads and load reductions achieved by controls for the site or watershed
- Program costs and cost per unit load removed

12 References Available

Northern Virginia Planning District Commission 1981 *Comparison of nonpoint pollution loadings from suburban and downtown central business districts* Annandale, VA

Northern Virginia Planning District Commission 1990 *Analysis of the recommended guidance calculation procedure for the Chesapeake Bay Preservation Act.* Draft report, Northern Virginia Planning District Commission. Annandale, VA

Schueler, T R 1987 *Controlling urban runoff: A practical manual for planning and designing urban BMPs* Metropolitan Washington Council of Governments Document No 87703, Washington, DC

USGS Regression Method

1 Name of Distributor.

Gary D Tasker
U S Geological Survey
430 National Center
Reston, VA 22092

2 Type of Modeling:

- Not a computer program
- Pollutant concentration from urbanized watersheds
- Statistical approach
- Annual, seasonal, or storm event mean pollutant loads
- Screening applications

3 Model Components

- Regression equations for mean storm event pollutant load estimation
- Confidence interval around the mean

4. Method/Techniques

Regression equations were developed from historical records of storm loads for 10 pollutants at 76 gaging stations in 20 States Ten explanatory parameters were used to reflect possible site variability associated with pollutant processes The nonuniformity of the variance required a generalized least squares analysis The general form of the regression model is as follows

$$W = 10^{[a + b\sqrt{DA} + cIA + dMAR + eMJT + fX_2]}\ BC,$$

where
W = mean storm event pollutant load
DA = watershed drainage area
IA = impervious area
MAR = mean annual rainfall
X_2 = indicator variable
BCF = bias correction factor
a,b,c,d,e,f = regression coefficients

The mean annual pollutant load can then be calculated by multiplying W by the mean annual number of storm events

5 Applications.

- Estimation of average mean annual storm event loads when data are severely limited
- Comparing different locations

6. Number of Pollutants·

Chemical oxygen demand, suspended solids, dissolved solids, total nitrogen, total ammonia-nitrogen (NH_3-N), total phosphorus, dissolved phosphorus, total copper, total lead, and total zinc

7. Limitations

- Valid only for areas for which regression coefficients are provided, i e , regional transferability is severely limited
- Valid only within the range of observed values of pollutant loads and explanatory variables
- Tends to underestimate the contributions of snowmelt or extreme events
- Does not address causation
- Applies only to small watersheds

8. Experience:

Limited

9. Updating Version:

N/A

10. Input Data Requirements:

- Drainage areas
- Percent imperviousness
- Mean annual rainfall
- Land use indicator
- Mean minimum January temperature
- Mean annual number of storm events

11. Simulation Output.

- Average annual storm event load and confidence interval

12 References Available:

Tasker, G D , and N E Driver 1988 Nationwide regression models for predicting urban runoff water quality at unmonitored sites *Water Resources Bulletin* 24(5) 1091-1101

Sediment and Phosphorus Prediction (SLOSS, PHOSPH)

1. Name of Distributor.

N/A (see reference below)

2 Type of Modeling

- Not a computer program
- Sediment yield and phosphorus loading from a watershed
- Annual simulation (may be adopted to storm events)
- It is used in combination with GIS capabilities
- Screening application

3. Model Components

- Two simple models for sediments and phosphorus

4 Method/Techniques

SLOSS uses the Universal Soil Loss Equation (USLE) to predict erosion and a sediment delivery ratio is used to estimate the sediment yield Phosphorus loading is calculated as the product of the average phosphorus content of the surface soil and a phosphorus enrichment ratio The unique feature of this approach is not the manner in which the pollutant loads are calculated but the ability to integrate simple algorithms with the Virginia Geographic Information System (VirGIS), which greatly facilitates parameter input.

5 Applications:

- Identify critical areas of pollutant production in watersheds
- Predict annual soil loss and phosphorus yields

6. Number of Pollutants:

- SLOSS predicts erosion and sediment yield
- PHOSPH predicts phosphorus loading

7 Limitations:

- Does not address seasonal variation
- Considers sediment and phosphorus only
- Requires access to GIS data

8 Experience:

Applied to Nomini Creek watershed in Westmoreland County, Virginia

9. Updating Version:

N/A

10. Input Data Requirements

- Parameters for the USLE (soil erodibility, cropping and management factors, topography, and rainfall erosivity factor) and channel parameters
- Phosphorus concentration in soil, phosphorus enrichment ratio

11. Simulation Output:

- Mean annual loads of sediment and phosphorus

12. References Available:

Tim, U.S , S. Mostaghimi, V O Shanholtz, and N Zhang 1991 Identification of critical nonpoint pollution source area using geographic information systems and simulation modeling In *Proceedings of The American Society of Agricultural Engineers (ASAE) International Summer Meeting,* Albuquerque, New Mexico, June 23-26, 1991.

Water Screen

1 Distributor:

Office of Planning and Zoning
Anne Arundel County
Annapolis, MD

2 Type of Modeling·

- Pollutant loading functions
- Screening application

3 Model Components

- Apple II computer program
- Modified USLE erosion and sediment yield
- Loading functions for nutrient and organic loadings

4 Method/Techniques

Loading factors are calculated for watersheds with sufficient data and applied to similar watersheds Sediment yield is estimated using the modified USLE and a delivery ratio The specific forms of the loading functions differ for nitrogen and phosphorus Phosphorus inputs are based on concentrations in eroded material and an enrichment ratio Nitrogen inputs include those associated with precipitation The loading function formulations are similar to those used in the EPA Screening Procedures (McElroy et al , 1976, and Zison et al , 1977)

5 Applications.

- Estimation of pollutant loadings
- Preplanning and screening applications

6. Number of Pollutants:

Phosphorus, nitrogen, metals, and organics

7 Limitations

- Cannot assess seasonal variability
- Limited to watersheds where data are available to calculate loading functions
- Limited documentation and applications

8 Experience

Water Screen has been applied on the Church Creek watershed south of Annapolis, Maryland, where it showed discrepancy between predictions of the MUSLE and the loading functions Either the loading functions for nitrogen and phosphorus or the factors used to estimate nitrogen and phosphorus concentrations in erosion predicted by the MUSLE were inappropriate for this watershed

9 Updating Version.

N/A

10 Input Data Requirements

- Parameters for the MUSLE including the rainfall factor (R) for all subwatersheds and land uses
- Sediment delivery ratios

- Nitrogen, phosphorus, and organic matter contents of eroded soils and enrichment ratios
- Atmospheric depositions
- Loading factors as a function of land use

11. Simulation Output

- Sediment, total nitrogen, total phosphorus, and organic (BOD and COD) yield for each land use

12. References Available:

Bird, B.L , and K M Conaway 1985 WATER SCREEN - A microcomputer program for estimating nutrient and pollutant loadings In *Proceedings of the Stormwater and Water Quality Model Users Group Meeting*, April 12-13, 1984 ed by T O Barnwell pp 121-174 EPA-600/9-85-0013

McElroy, A D , D S Chiu, J W Nebgen, A Aleti, and F W Bennett 1976 *Loading functions for assessment of water pollution from nonpoint sources.* U S Environmental Protection Agency, Washington, DC EPA-600/2-76-151

Zison, S W , K F Haven, and W.B Mills 1977 *Water quality assessment - A screening method for nondesignated 208 areas* U S Environmental Protection Agency, Athens, GA EPA600/9-77-023

WATERSHED

1. Distributor.

John F Walker
U S Geological Survey
6417 Normandy Lane
Madison, WI 53719-1133
(608) 274-3535

2. Type of Modeling:

- Various multiple point sources plus continuous and diffuse source/release
- Screening application

3 Model Components·

- Program is divided into seven worksheets. The first summarizes basic watershed characteristics The next three worksheets estimate pollutant loads from point sources and cropland and non-cropland agricultural land uses for controlled and uncontrolled conditions. Sources are totaled for controlled and uncontrolled conditions by worksheet 5
- Program costs and cost-effectiveness per unit load reduction are also calculated

4 Method/Techniques

Separate methods are used to calculate urban, rural non-cropland, and rural cropland loads Urban loads are calculated from point estimates of flow and concentration, rural non-cropland loads are estimated on a unit area basis, and rural cropland loads are based on the Universal Soil Loss Equation (USLE) The rainfall factor (R) in the USLE is unspecified for use as a calibration parameter Delivery ratios and trapping efficiencies for tributary wetlands are used to convert eroded sediment to sediment delivered These values are also calibrated The model used the sorting features of the EXCEL® spreadsheet program for the Macintosh computer to rank the most cost-effective alternatives

5 Applications:

- Phosphorus loading from point sources, CSOs, septic tanks, rural cropland, and non-cropland rural sources was estimated for Delavan Lake watershed in Wisconsin
- Evaluation of the trade-offs between control of point and nonpoint sources

6 Number of Pollutants:

Used for only one at a time, e g phosphorus

7 Limitations:

- Cannot assess seasonal variability
- Can assess only a limited number of land management control practices
- Requires calibration to determine the rainfall factor and the sediment delivery ratio
- Can assess only contaminants associated with soils and sediments

8. Experience:

Watershed was applied to the study of point and nonpoint sources in the Delavan Lake watershed in Wisconsin It was determined that runoff controls would be insufficient to meet water quality standards Instead of focusing controls for phosphorus on nonpoint sources, the study recommended several in-lake controls

9. Updating Version

N/A

10. Input Data Requirements:

- Sources of pollution along with their respective position and point of entry to the basin
- Flows and concentrations of point sources
- Areas served by urban land uses such as storm sewers, combined sewers, and unsewered areas along with their corresponding unit area loads for the pollutant of concern
- Areas and unit area loads for grass and woodland areas
- Parameters for the USLE for croplands
- Pollutant delivery ratios and pollutant reduction efficiency ratio
- Treatment schemes and associated costs

11. Simulation Output.

- Total annual loads and load reductions achieved by controls for the site or watershed
- Program costs and cost per unit load removed

12 References Available·

Walker, J F , S A Pickard, and W C Sonzogni 1989 Spreadsheet watershed modeling for nonpoint-source pollution management in a Wisconsin basin *Water Resources Bulletin* 25(1) 139-147

FHWA: The Federal Highway Administration Model

1. Distributor.

Office of Engineering and Highway
Operations R&D
Federal Highway Administration
6300 Georgetown Pike
McLean, VA 22101

2 Type of Modeling

- Statistical
- Screening application

3 Model Components

- Computation of water quality impact from site data for either lakes or streams
- Simple evaluation of controls

4 Method/Techniques.

Pollutant loadings and the variability of loadings are estimated from runoff volume distributions and event mean concentrations for the median runoff event at a site. Rainfall is converted to runoff using a runoff coefficient calculated from the percent imperviousness Runoff velocity is estimated from runoff intensity. Mean runoff concentrations are calculated from site median pollutant concentrations, coefficient of variation for event mean concentrations (EMCs), and the mean EMC as

$$MCR = TCR \cdot \sqrt{(1 + CVCR^2)}$$

where
MCR = mean EMC for site (mg/L)
TCR = site median pollutant concentration (mg/L)
CVCR = coefficient of variation of EMCs

Mean event mass loading is computed as

$$M(Mass) = MCR \cdot MVR \cdot (62\ 45 \cdot 10^{-6})$$

where
M(Mass) = mean pollutant mass loading (pounds per event)
MCR = mean runoff concentration (mg/L)
MVR = mean storm event runoff volume (cf)

Annual loads are calculated by multiplying by the number of storms per year Pollutant build-up is based on traffic volumes and surrounding area characteristics

5 Applications

- Evaluation of lake and stream impacts of highway stormwater discharges
- Uncertainty analysis of runoff and pollutant concentrations, or loads
- Highway stormwater runoff management

6 Number of Pollutants.

Heavy metals (copper, lead, and zinc), nitrogen, and phosphorus

7 Limitations:

- Assesses seasonal variability in a limited manner as expressed in the probability distributions of the output
- Limited in its evaluation of controls

- Does not consider the soluble fraction of pollutants or the precipitation and settling of phosphorus in lakes

8. Experience:

The FHWA model was used by the Federal Highway Administration to evaluate the impacts of stormwater runoff from highways and their surrounding drainage areas

9. Updating Version:

N/A

10. Input Data Requirements·

- Hourly rainfall data to be transformed into mean and coefficient of variation
- Drainage and paved areas, average rainfall volumes, intensities, and durations
- Coefficients of variation are required for all average rainfall characteristics
- Traffic volumes for the surrounding area are required
- Runoff concentrations (average and coefficient of variations) for each pollutant

11 Simulation Output

- Mean and variance of in-stream or lake concentrations
- Mean and variance of pollutant loadings and concentrations in runoff

12 References Available

Driscoll, E D , P E Shelley, and E W Strecker 1990 *Pollutant loadings and impacts from highway stormwater runoff, Volume I. Design procedure* Prepared for the Office of Engineering and Highway Operations R&D, Federal Highway Administration

Driscoll, E D , P E Shelley and E W Strecker 1990 *Pollutant loadings and impacts from highway stormwater runoff, Volume II. Users guide for interactive computer implementation of design procedure* Prepared for the Office of Engineering and Highway Operations R&D, Federal Highway Administration

WMM: Watershed Management Model

1 Distributor:

Prepared by Camp Dresser & McKee Inc for Stormwater Management Division, Florida Department of Environmental Regulation
Twin Towers Office Building
2600 Blair Stone Road
Tallahassee, Florida 32301-8241
(904) 488-6221

2. Type of Modeling:

- Watershed stormwater pollutant loads
- Multiple diffuse source release
- Annual time steps
- Screening application

3. Model Components

- Computation of annual nutrient and metal loads to reservoirs
- Computation of in-lake or in-stream water quality from pollutant loads
- Load reduction estimates for site or regional BMP implementation
- Uptake and removal in stream courses
- Estimates of annual pollutant loads from baseflow
- Comparison with point sources
- Failing septic tank loads
- Chlorophyll-*a* and nutrient concentrations in downstream lakes and reservoirs

4. Method/Techniques.

Runoff coefficients are used for rural areas, for urban areas runoff is based on a linear function of the percent imperviousness Loading of nutrients and metals is based on event mean concentrations measured locally or from NURP data Baseflow is estimated from flow records and concentrations There is a choice of three lake water quality routines that output mean annual concentrations of chlorophyll-*a.* (The model can be adapted to predict seasonal loads or chlorophyll-*a* concentrations provided that seasonal event mean concentration data are available) Simple calculations are included for in-stream transport and transformation based on travel time The program can assess the relative contributions of point and nonpoint sources Resultant water quality is predicted with a version of the Vollenweider eutrophication model, adapted to lakes in the southeastern United States Removal of metals associated with sediments in reservoirs is estimated from the sediment-trapping efficiency of the reservoir

5 Applications:

Estimates the annual nonpoint source loads, including baseflow and precipitation inputs, for management planning

6. Number of Pollutants

Total phosphorus, total nitrogen, lead, and zinc

7. Limitations

- Accuracy is limited when default parameters are substituted for site-specific data
- Neglects seasonal variation
- Does not predict sediment yields

- Does not evaluate control practices except through assumption of a constant removal fraction
- Does not consider loadings associated with snowmelt events
- Can assess only relative impacts of land use categories or controls

8. Experience:

The model has been applied to between 10 and 15 watersheds It has been used as part of a wasteload allocation study for Lake Tohopekaliga and for Jacksonville, Florida, watershed's Master Plan. It has been applied in Norfolk County, Virginia, and to a Watershed Management Plan for North Carolina

9. Updating Version

Under development

10. Input Data Requirements

- Land use and soil types
- Average annual precipitation, evaporation, and evapotranspiration
- Nutrient concentrations in precipitation
- Annual baseflow and baseflow pollutant concentrations
- Event mean concentrations in runoff
- Reservoir, lake, or stream hydraulic characteristics
- Removal efficiencies of proposed BMPs

11 Simulation Output

- Annual pollutant loads from point and nonpoint sources, including both agricultural and urban land use
- Relative magnitude of inputs from point sources and septic tanks
- Load reductions from combined effects of multiple BMPs
- In-lake nutrient concentrations as related to trophic state, also, concentrations of metals are evaluated for the reservoir
- Standard statistics and bar graphs of results

12. References Available

Camp, Dresser and McKee (CDM) 1992 *Watershed Management Model user's manual, Version 2 0* Prepared for the Florida Department of Environmental Regulation, Tallahassee, FL

NPSMAP: Nonpoint Pollution Source Model for Analysis and Planning

1 Distributor

Dr Jack Douglas Smith
Project Manager
Water Resources/Quality
Fetrow Engineering, Inc
12300 S E Mallard Way, Suite 205
Milwaukee, OR 97222
(503) 652-1526

2 Type of Modeling

- Multiple land use watersheds
- Water quality analysis
- Continuous simulation (hourly data, one year at a time)
- Point and nonpoint sources
- Wasteload and load allocations
- Screening application

3. Model Components:

- Runoff and pollutant loading assessment
- Water quality and resources management analysis
- Simulation of wet detention or wetland system controls for each subbasin or stream segment
- Irrigation and drainage
- Snowfall and snowmelt
- Uses Lotus 1-2-3® spreadsheet

4. Method/Techniques

NPSMAP is a spreadsheet-based program that operates within the Lotus 1-2-3® programming environment NPSMAP is a dynamic simulation program that includes three primary computation modules (SIMULATE, ALLOCATE, and PROBABILITY). SIMULATE computes daily runoff, pollutant loadings, streamflow, and water quality ALLOCATE simulates stream segment load capacities (LCs), point source wasteload allocations (WLAs), and nonpoint source load allocations (LAs) PROBABILITY computes the probability distributions of runoff and loadings

5 Applications

- Nonpoint source runoff and pollutant (nutrient) loadings, including surface water storage in reservoirs and wetlands
- Point source discharges and streamflow
- Groundwater levels, irrigation and other water uses, and water quality

6 Number of Pollutants·

Nitrogen and phosphorus

7 Limitations.

- No sediment is evaluated
- Limit on simulation period (one year at a time)

8 Experience

Applied to the Tualatin River basin for Oregon Department of Environmental Quality

9 Updating Version

Version 1 0 (1990)

10. Input Data Requirements.

- Hydrology data stream segment volumes and streamflow recession coefficients, parameters for upland groundwater, parameters and exchange matrix for valley fill groundwater model, and rainfall intensity
- Land use data land use distributions and parameter values in each stream segment, soil parameters, and SCS curve number and retention coefficients
- Weather records including rainfall, snowfall, temperature, and evapotranspiration

11. Simulation Output

- Daily runoff and streamflow
- Nonpoint source runoff and loads
- Treatment plant discharges, loadings, overflows/bypasses
- Groundwater, streamflow, and water quality (loads and concentrations)
- Bar graphs, two- and three-dimensional graphs are available for simulation results
- Statistical summary
- Probability distributions of runoff and loadings
- Stream segment load capacities (LCs), point source wasteload allocations (WLAs), and nonpoint source load allocations(LAs)

12 References Available

Omicron Associates 1990 *Nonpoint Pollution Source Model for Analysis and Planning (NPSMAP) - Users manual* Omicron Associates, 11265 NW Rainmont Road, Portland, OR

GWLF: Generalized Watershed Loading Functions

1 Distributor·

Dr Douglas A Haith
Department of Agricultural and
Biological Engineering
Cornell University
Ithaca, NY 14853
(607) 255-2802

2 Type of Modeling

- Pollutant loads from urban and agricultural watersheds
- Continuous simulation using daily time step
- Point and nonpoint sources
- Screening to intermediate application
- Evaluation of effects of land use changes

3 Model Components:

- Rainfall/runoff assessment
- Surface water/groundwater quality analysis

4. Method/Techniques

This model is based on simple runoff, sediment, and groundwater relationships combined with empirical chemical parameters. It evaluates streamflow, nutrients, soil erosion, and sediment yield values from complex watersheds Runoff is calculated by means of the SCS curve number equation The Universal Soil Loss Equation (USLE) is applied to simulate erosion Urban nutrient loads are computed by exponential wash-off functions. Groundwater runoff and discharge are obtained from a lumped-parameter watershed water balance for both shallow saturated and unsaturated zones Calibration is not required for water quality data

5. Applications:

Relatively large watersheds with multiple land uses and point sources

6. Number of Pollutants:

Total and dissolved nutrients (nitrogen and phosphorus) and sediment

7. Limitations:

- Simulation of peak nutrient fluxes is weak
- Stormwater storage and treatment are not considered

8 Experience:

GWLF was validated for an 85,000-hectare watershed from the West Branch Delaware River Basin in New York using a 3-year period of record

9. Updating Version

Under development

10. Input Data Requirements.

- Daily precipitation and temperature data and runoff source areas
- Transport parameters· runoff curve numbers, soil loss factor, evapotranspiration cover coefficient, erosion product, groundwater recession

and seepage coefficients, and sediment delivery ratio

- Chemical parameters urban nutrient accumulation rates, dissolved nutrient concentrations in runoff, and solid-phase nutrient concentrations in sediment
- Point sources

11. Simulation Output·

- Annual and seasonal runoff, streamflow, watershed erosion, and sediment yield
- Annual and seasonal total and dissolved nitrogen and phophorus loads in streamflow and groundwater discharge to streamflow
- Annual erosion and total/dissolved nitrogen and phosphorus loads from each land use
- Annual and seasonal pollutant loadings by land use type and pollution sources

12. References Available

Brown, M P., M.R Rafferty, and P Longabucco. 1985 *Nonpoint source control of phosphorus - A watershed evaluation.* Report to the U S Environmental Protection Agency, Ada, OK.

Delwiche, L L D and D A Haith. 1983 Loading functions for predicting nutrient losses from complex watersheds *Water Resources Bulletin* 19(6) 951-959

Haith, D A 1985 An event-based procedure for estimating monthly sediment yields *Transactions of the American Society of Agricultural Engineers* 28(6) 1916-1920

Haith, D A and L L Shoemaker 1987 Generalized watershed loading functions for stream flow nutrients *Water Resources Bulletin* 23(3) 471-478

Haith, D A and L J Tubbs 1981 Watershed loading functions for nonpoint sources *Proceedings of the American Society of Civil Engineers* Journal of the Environmental Engineering Division 107(EE1) 121-137

Wu, S R , D A Haith, and J H Martin, Jr 1989 *GWLF - Generalized Watershed Loading Functions - User's manual.* Department of Agricultural Engineering, Cornell University, Ithaca, NY

P8-UCM: Urban Catchment Model

1 Distributor

Narragansett Bay Project
291 Promenade Street
Providence, RI 02908-5767
(401) 521-4230

2. Type of Modeling

- Urban watersheds
- Storm event/sequence simulation
- Surface water quality analysis
- Evaluation of BMPs and development of design criteria
- Single, continuous, and diffuse source/release
- Screening application

3 Model Components:

- Rainfall, stormwater runoff assessment
- Surface water quality analysis
- Routing through structural controls

4 Method/Techniques

The P8 program predicts the generation and transport of stormwater runoff pollutants in small urban catchments It consists mainly of methods derived from other tested urban runoff models (i e , SWMM, HSPF, D3RM, TR-20). Runoff from impervious areas is calculated directly from rainfall once depression storage is exceeded Particle build-up and wash-off processes are obtained using equations derived primarily from the SWMM program The SCS curve number equation is used to predict runoff from pervious areas Water balance calculates percolation from the pervious areas Baseflow is simulated by a linear reservoir Without calibration, use of model results should be limited to relative comparisons

5 Applications

- Surface water quantity and quality routing
- Small urban area assessments
- Watershed-scale land use planning
- Site planning and evaluation for compliance
- Selecting and sizing BMPs

6. Number of Pollutants:

Ten pollutants, including total suspended solids (TSS), total phosphorus, total Kjeldahl nitrogen, lead, copper, zinc, and hydrocarbons

7 Limitations.

- No snowfall, snowmelt, or erosion is calculated
- Effects of variations in vegetation type/ cover on evapotranspiration are not considered
- Watershed lag is not simulated

8 Experience:

N/A

9. Updating Version

Version 1 1 (1990)

10. Input Data Requirements.

- Device (hydraulic) parameters for pond, basin, buffer, pipe, splitter, and aquifer
- Watershed parameters areas, impervious fraction and depression storage, street-sweeping frequency, SCS runoff curve number for pervious portion
- Particle parameters accumulation/wash-off parameters, runoff concentrations, street-sweeper efficiencies, settling velocities, decay rates, filtration efficiencies
- Water quality component parameters pollutant concentrations
- Air temperatures required for stream baseflow computations

11. Simulation Output:

- Water and mass balances, removal efficiencies, mean inflow/outflow concentrations, and statistical summaries by device and component
- Comparison of flow, loads, and concentration across devices
- Peak elevation and outflow ranges for each device
- Sediment accumulation rates by device
- Violation frequencies for event mean concentrations

12. References Available

Palmstrom, N , and W W Walker, Jr 1990 *P8 Urban Catchment Model: User's guide, program documentation, and evaluation of existing models, design concepts, and Hunt-Potowomut data inventory.* The Narragansett Bay Project Report No NBP-90-50

SIMPTM: Simplified Particle Transport Model

1. Distributor·

Roger C Sutherland
Software Distribution
OTAK, Inc
17355 Boones Ferry Road
Lake Oswego, OR 97035
(503) 635-3618
Cost: $495

2 Type of Modeling.

- Stormwater from urban watersheds
- Storm event/sequence simulation
- Continuous and diffuse source release
- Screening applications
- Evaluation of BMPs

3 Model Components.

- Rainfall/runoff assessment
- Surface water quality analysis

4 Method/Techniques

SIMPTM simulates the accumulation, wash-off, and mechanical removal of up to six different pollutants contained in total solids or particulate matter accumulating on paved areas that are directly connected to storm drain systems Runoff is calculated using runoff thresholds and originates only from paved areas directly connected to storm drain systems SIMPTM converts event trapezoidal hyetographs into trapezoidal hydrographs using the runoff duration and small storm impervious area loss equations developed by Pitt (1987) Street cleaning, catchbasin accumulation, and on-site retention are expressed as a function of particle size distribution Simulation of runoff or pollutant loads from pervious areas and baseflow is ignored

5 Applications:

- Simulation of runoff and sediment yields from urban watersheds with small, storm-based hydrology
- Effectiveness of various, primarily nonstructural controls, such as street and catchment cleaning

6. Number of Pollutants

Six pollutants including sediment components, nitrogen, phosphorus, chemical oxygen demand

7 Limitations:

- Snow accumulation and snowmelt are ignored in the hydrology simulation
- Nutrient transformations are not evaluated
- Runoff and pollutants are assumed to originate solely from impervious areas directly connected to the drainage system
- Model testing in Pacific Northwest only

8 Experience.

The model was calibrated using National Urban Runoff Program (NURP) data from the Lake Hills basin in Bellevue, Washington Subsequently, the model was tested using NURP data for the Surrey Downs basin, also in the Bellevue area The simulation of variability of runoff events was excellent considering the simplistic approach used to convert rainfall into runoff volumes The predicted variability in pollutant loads was less variable than was actually observed.

Version 1 (1980) was applied to over 57,000 acres of urban and urbanizing land surrounding Reno, Nevada, for the Washoe County Council of Governments for the purpose of comprehensive stormwater management

9. Updating Version:

Version 2 1 November 1990

10. Input Data Requirements:

- Rainfall depths for 1-, 3-, or 6-hour periods
- Pollutant strengths and accumulation and wash-off parameters
- Particle size distributions
- Curb lengths and characterization of impervious surfaces

11. Simulation Output:

- Runoff volumes, durations, pollutant loadings, and event mean concentrations for each rainfall event
- Results may be reported for each subcatchment or for the entire watershed
- Although graphic output is not available, results can be imported to spreadsheets, such as Lotus 1-2-3®
- Average monthly and annual statistics are calculated for rainfall depths, durations, and intensities

12 References Available:

Pitt, R E 1987 *Small storm urban flow and particulate wash-off contributions to outfall discharges* Ph D Dissertation, Civil and Environmental Engineering Department, University of Wisconsin, Madison, November 1987

Sutherland, R C , D L Green, and S L Jelen 1990 *Simplified Particulate Transport Model, Users manual* OTAK, Inc Lake Oswego, Oregon

Sutherland, R C 1991 Modeling of urban runoff quality in Bellevue, Washington using SIMPTM In *Proceedings from the technical sessions of the regional conference on nonpoint source pollution: The unfinished agenda for the protection of our water quality*, March 20-21, 1991, Tacoma, WA Published by the State of Washington Water Research Center

Automated Q-ILLUDAS (AUTO-QI)

1 Distributor.

Michael L Terstriep
Illinois State Water Survey
2204 Griffith Drive
Champaign, Illinois 61820-7495
Cost $50

2 Type of Modeling

- Urban stormwater processes
- Storm event simulation
- Continuous and diffuse pollutant sources
- Screening and intermediate applications
- Evaluation of BMPs

3 Model Components

- Rainfall/runoff assessment from pervious and impervious areas
- Water quality analysis (emphasis on nutrients and sediments)
- Simulation of BMPs, separate or overlapping
- Linkage to geographic information system (GIS)

4 Method/Techniques

AUTO-QI is based on continuous simulation of soil moisture Runoff volumes are adjusted for soil moisture, pervious and impervious depression storage, interception, and infiltration based on Horton infiltration curves Exponential pollutant accumulation and wash-off functions are used to determine the pollutant loads The impacts of a series of pollutant reduction practices are simulated based on user-supplied removal efficiencies

5 Applications·

- Simulation of runoff volumes, pollutant loads, and event mean concentrations
- Comparison of pollutant levels with and without BMPs and with various fertilizer application rates

6 Number of Pollutants.

Several pollutants including nitrogen, phosphorus, chemical oxygen demand (COD), metals, and bacteria (at least three at once)

7 Limitations·

- Does not calculate pollutant removal efficiencies, removal efficiencies must be supplied by the user
- Lacks nutrient transformation and instream processes
- Tested in the State of Illinois only
- No simulation of subsurface soil processes

8. Experience

Simulation of urban pollutant loads for suspended solids, phosphorus, and lead from the greater Lake Calumet area after calibration on Boneyard Creek in Champaign, Illinois (1990)

9. Updating Version:

October 1990

10. Input Data Requirements:

- Daily and hourly rainfall data
- Monthly evaporation and evapotranspiration values
- BMP removal efficiencies
- Soil infiltration parameters
- Land use parameters and soil types for each subcatchment
- Build-up and wash-off characteristics of each pollutant

11. Simulation Output:

- A summary for the watershed by event is created for rainfall, runoff, and runoff duration
- Event mean concentrations and loadings

12. References Available.

Terstriep, M. L , M T Lee, E P Mills, A V Greene, and M R. Rahman 1990 *Simulation of urban runoff and pollutant loading from the Greater Lake Calumet area* Prepared by the Illinois State Water Survey for the U S Environmental Protection Agency, Region V, Water Division, Watershed Management Unit, Chicago, IL

AGNPS: Agricultural Nonpoint Source Pollution Model

1 Distributor

Basil Meyer
North Central Soil
Conservation Research Laboratory
U S Dept of Agriculture
Agricultural Research Service
Morris, MN 56267
(612) 589-3411

2 Type of Modeling

- Simulation of pollutant loads from agricultural watersheds
- Storm-event simulation
- Point source/release
- Distributed modeling using a grid system with square elements
- Screening, intermediate, and detailed applications
- Evaluation of BMPs

3 Model Components

- Rainfall/runoff assessment
- Water quality analysis (emphasis on nutrients and sediments)
- Point source inputs available (feedlots, springs, wastewater treatment plant discharge, bank and gully erosion)
- Unsaturated/saturated zone routines
- Economic analysis
- Linkage to GIS possible

4 Method/Techniques

This model can identify critical areas of sediment and nutrient production in a watershed and can assess the impacts of best management practices (BMPs). Soil erosion is simulated by the modified Universal Soil Loss Equation (USLE) The unit hydrograph approach is used to predict water flow, while the SCS curve number equation is applied to estimate runoff volume Some versions are linked to GIS and DEM with automatic generation of terrain parameters (Panuska et al , 1991)

5 Applications

- Erosion, sediment, and chemical transport
- Surface water flow routing

6 Number of Pollutants

Four pollutants nitrogen, phosphorus, chemical oxygen demand (COD), and sediment

7 Limitations

- Only single event version is currently available, although a continuous simulation version (ANNAGNPS) should be released soon
- Does not handle pesticides
- Lacks nutrient transformation and instream processes
- Needs further field testing for pollutant transport component
- No simulation of subsurface soil processes
- Rainfall intensity is not considered in the runoff analysis

8. Experience.

- Economic assessment of soil erosion and water quality in Idaho (1987)

- Economic effect of nonpoint pollution control alternatives (1988)
- Analysis of agricultural nonpoint pollution control options in St Albans Bay, Vermont (1987)
- Water quality evaluation of Garvin Brook watershed (1989)
- Alternative management practices in Salmonson Creek watershed (1989)
- Applied along with a GIS to the Owl Run watershed, which is part of the Chesapeake Bay watershed, to predict the effectiveness of BMP installation

9. Updating Version

Single event AGNPS Version 3 65
Soon to be released are AGNPS Version 4 0 (written in C) and continuous simulation AGNPS (ANNAGNPS)

10. Input Data Requirements

- Topography and soil characteristics
- Meteorologic data
- Land use data (cropping history and nutrient applications)
- Point source data

11. Simulation Output

- Hydrology output storm runoff volume and peak rate
- Sediment output sediment yield, concentration, particle size distribution, upland erosion, amount of deposition
- Chemical output pollutant concentration and load

12. References Available

Frevert, K and B M Crowder 1987 *Analysis of agriculture nonpoint pollution control options in the St. Albans Bay watershed* Economic Division, ERS, USDA, Staff Report No AGES870423

Hewitt, M J 1991 GIS for nonpoint source watershed modeling applications *In EPA Workshop on the Water Quality-based Approach for Point Source and Nonpoint Source Controls*, June 1991, p 34 EPA503/9-92-001

Kozloff, K , S J Taff, and W Wang 1992 Microtargeting the acquistion of cropping rights to reduce nonpoint source water pollution *Water Resources Research* 28(3) 623-628

Lee, M T 1987 Verification and applications of a nonpoint source pollution model In *Proceedings of the National Engineering Hydrology Symposium*, ASCE, New York, NY

Panuska, J C , I D Moore, and L A Kramer 1991 Terrain analysis Integration into the agricultural nonpoint source (AGNPS) pollution model *Journal of Soil and Water Conservation* 46(1) 59-64

Prato, T , H Shi, R Rhew, and M Brusven 1989 Soil erosion and nonpoint-source pollution control in an Idaho watershed *Journal of Soil Water Conservation* 44(4) 323-328

Setia, P P , R S Magleby, R S , and D G Carvey 1988 *Illinois rural clean water project - An economic analysis* Resources and Technology Division, ERS, USDA Staff Report No AGES830617

Young, R A , C A Onstad, D D Bosch, and W P Anderson 1986 *Agricultural Nonpoint Source Pollution Model A watershed analysis tool* Agriculture Research Service, U S Department of Agriculture, Morris, MN

SLAMM: Source Loading and Management Model

1 Distributor

Dr Robert Pitt
Department of Civil Engineering
University Station
Birmingham, AL
(205) 934-8430

2 Type of Modeling

- Continuous and diffuse source/release
- Continuous series of storm events (up to 150)
- Screening application
- Evaluation of controls

3 Model Components

- Rainfall/runoff assessment
- Water quality analysis

4 Method/Techniques.

This program can evaluate the effects of a number of different stormwater control practices on runoff routines SLAMM performs continuous mass balances for particulate and dissolved pollutants and runoff volumes Runoff is calculated by a method developed by Pitt (1987) for small storm hydrology Runoff is based on infiltration minus initial abstraction and is calculated for both pervious and impervious areas Triangular hydrography is used to simulate the hydrology A statistical approach is used to parametrize the hydrographs Exponential build-up and wash-off functions are used for pollutant loading, which is assumed to come from impervious areas Loading from pervious areas is constant concentration supplied by user Water and sediment from various source areas is tracked by source area as it is routed through various treatment devices The program considers how particulates filter or settle out in control devices Particulate removal is calculated based on the design characteristics of the basin or other removal device Storage and overflow of devices is also considered At the outfall locations, the characteristics of the source areas are used to determine pollutant loads in solid and dissolved phases Loads from various source areas are summed

5 Applications

- Evaluates multiple control strategies such as wet detention basins, porous pavement, infiltration devices, street cleaning, catchment cleaning, grass swales, roof runoff disconnections, and paved parking lot disconnections
- Planning tool for urban runoff quality and quantity assessments
- Applicable to the study of stormwater pollutant control from regions frequently receiving rainfall events of less than 1 inch

6. Number of Pollutants

Particulate and dissolved pollutants (depending on the calibration information), such as particulate and filterable forms of residue, phosphorus, phosphate, total Kjeldahl nitrogen, chemical oxygen demand (COD), fecal coliform bacteria, aluminum, copper, lead, and zinc

7. Limitations:

- Does not evaluate snowmelt and baseflow conditions
- Will not provide individual storm predictions
- Evaluates runoff characteristics at the source area within the watershed and at the discharge outfall but does not consider instream processes that remove or transform pollutants
- Does not evaluate receiving water quality responses
- Requires between 10 and 100 storms in a study period (maximum 150)
- Does not develop or evaluate specific hydraulic designs
- Does not model erosion from pervious areas or construction sites

8. Experience.

SLAMM has been used in conjunction with receiving water quality models (HSPF) to examine the ultimate effects on urban runoff from Toronto for the Ontario Ministry of the Environment SLAMM was also used to evaluate control options for controlling urban runoff in Madison, Wisconsin, using GIS information The State of Wisconsin uses SLAMM as part of its Priority Watershed Program It was used in Portland, Oregon, for a study evaluating CSOs.

9. Updating Version:

Currently being updated

10. Input Data Requirements:

- Rainfall start and end dates (and times) and rainfall depths
- Areas of each source type, effective SCS soil type
- Building and traffic density
- Pavement texture, roof pitch, and presence of alleys
- Land use
- Shape, size, and type of outlet structures of the wet detention basin
- Soil infiltration rates for infiltration devices

11 Simulation Output·

- Source area and outfall flow volume estimates for each rainfall period and land use
- Source area and outfall particulate residue mass discharge and concentration estimates for each rainfall period and land use
- Relative source area runoff volume and particulate residue mass contribution estimates for each rainfall period
- Mass discharge, concentration, and relative contribution estimates for each pollutant selected
- Cost estimates of stormwater control practices, graphical summaries, baseflow predictions, and snowmelt predictions are under development

12 References

Pitt, R 1979 *Demonstration of non-point pollution abatement through improved street cleaning practices* U S Environmental Protection Agency, Cincinnati, OH PA-600/2-79-161 (NTIS PB80-108988)

Pitt, R 1986 Runoff controls in Wisconsin's priority watersheds In *Urban runoff quality,* ed B Urbonas, and L A Roesner, Proceedings of the Engineering Foundation Conference on Urban Runoff Quality (ASCE), June 22-27, 1986, in Henniker, NH.

STORM: Storage, Treatment, Overflow, Runoff Model

1. Distributor:

U S Army Corps of Engineers
The Hydrologic Engineering Center (HEC)
609 Second Street
Davis, CA 95616
Cost. $200 - 9-track magnetic tape

2 Type of Modeling

- Urban runoff processes
- Continuous simulation (hourly time steps)
- Continuous and diffuse source/release
- Screening application

3 Model Components·

- Rainfall/runoff assessment
- Water quality analysis
- Statistical and sensitivity analysis

4 Method/Techniques.

This is a quasi-dynamic program A modified rational formula is used for hydrology simulation Rainfall/runoff depth and volumes are computed by means of an area-weighted runoff coefficient and the SCS curve number equation, respectively The Universal Soil Loss Equation (USLE) is applied to simulate erosion Water quality is simulated by linear build-up and first-order exponential wash-off coefficients Calibration is advisable, but relative comparisons can be evaluated without calibration

5. Applications:

- Storm and combined sewer overflows including dry-weather flow
- Surface water quantity and quality routing with storage/treatment option
- Urban areas assessments

6 Number of Pollutants

Six prespecified pollutants suspended solids, settleable solids, BOD, total coliforms, ortho-phosphate, and total nitrogen

7. Limitations

- Little flexibility in parameters to calibrate to observed hydrographs
- Lacks microcomputer version
- Requires a large amount of input data

8 Experience:

STORM was extensively used in the late 1970s and early 1980s. The model was applied to the San Francisco master drainage plan for abatement of combined sewer overflows

9 Updating Version

Version 1 (1977)

10. Input Data Requirements:

- SCS, build-up, and wash-off parameters
- Runoff coefficient and soil type

11. Simulation Output:

- Storm event summaries (runoff volume, concentrations, and loads)
- Summaries of storage and treatment, utilization, total overflow loads and concentrations
- Hourly hydrographs and pollutographs (concentration vs time)
- Statistical summaries on annual and total simulation period basis (percentage of runoff passing through storage and the number of overflows)

12. References Available:

Abbott, J 1977 *Guidelines for calibration and application of STORM.* U.S. Army Corps of Engineers, Hydrologic Engineering Center Davis, CA Training Document No 8

Abbott, J 1978. *Testing of several runoff models on an urban watershed.* ASCE Urban Water Resources Research Program. ASCE, New York, NY Technical Memorandum No 34

Donigian, A S , Jr , and W C Huber 1991 *Modeling of nonpoint source water quality in urban and non-urban areas.* U S Environmental Protection Agency, Environmental Research Laboratory, Athens, Georgia EPA/600/3-91/039

Hydrologic Engineering Center. 1977 *Storage, Treatment, Overflow, Runoff Model, STORM, User's manual.* Generalized Computer Program 723-S8-L7520 U S Army Corps of Engineers, Davis, CA

Najarian, T O , T T Griffin, and V K Gunawardana 1986 Development impacts on water quality A case study *Journal of Water Resources Planning and Management,* ASCE, 112(1) 20-35

Shubinski, R P , A J Knepp, and C R Bristol 1977 *Computer program documentation for the continuous storm runoff model SEM-STORM* Report to the Southeast Michigan Council of Governments, Detroit, MI

ANSWERS: Areal Nonpoint Source Watershed Environment Response Simulation

1. Distributor

Dr David Beasley
Department of Agriculture Engineering
North Carolina State University
Raleigh, North Carolina
(919) 515-2694

2 Type of Modeling

- Simulation of agricultural watersheds with emphasis on erosion and sediment yield
- Distributed simulation using a grid system
- Storm event simulation
- Single and diffuse source/release
- Screening and intermediate applications
- Evaluation of BMPs

3 Model Components:

- Rainfall/runoff assessment
- Overland flow and channel flow
- Loading of nutrients and pesticides
- Erosion, sediment transport, and deposition

4 Method/Techniques

This model simulates the effects of land use, management, and conservation practices on the quality and quantity of water in a watershed The hydrology component is based on surface and subsurface water movement relationships using a modified form of the Holton infiltration model Erosion processes are predicted by an event-based particle detachment and transport model The quality component was added to the model to compute pollutant loadings based on correlation relationships between concentration, sediment yield, and runoff volume Improvements to the pollutant loading and transformation routines have been incorporated by Dillaha et al (1988)

5 Applications

- Hydrologic and erosion response of agriculture land and construction sites
- Movement of water in overland, subsurface, and channel flow phases
- Identification of critical areas for erosion and sedimentation control
- Siting and evaluation of BMPs

6 Number of Pollutants

Nutrients (phosphorus and nitrogen) and sediment (Some versions include pesticides)

7 Limitations:

- Mainframe computer required for large watershed simulation
- Complexity of input data file
- Snowmelt processes and pesticide modeling are not included
- No chemical transformation of nitrogen and phosphorus
- Small time steps are necessary for finite difference algorithms and restrict the simulation to a single event

- Requires small element grid, assumes homogeneous condition within each element

8. Experience:

Applied successfully in Indiana on agricultural watersheds and construction sites for best management practice (BMP) evaluation Evaluated the relative importance of point and nonpoint source contributions to Saginaw Bay

9. Updating Version:

N/A

10. Input Data Requirements

Detailed description of the watershed topography, drainage network, soils, and land use (available from USDA-SCS soil surveys, land use, and cropping surveys)

11 Simulation Output:

- Alternative erosion control management practices on an element basis or entire watersheds (flow and sediment)
- Limited graphical representation of output results

12. References Available.

Amin-Sichani, S. 1982 *Modeling of phosphorus transport in surface runoff from agricultural watersheds* Ph D Thesis, Purdue University, W Lafayette, IN.

Beasley, D.B and L F Huggins 1981 *ANSWERS User's Manual.* U S Environmental Protection Agency, Region V Chicago, IL EPA905/9-82-001

Beasley, D B 1986 Distributed parameter hydrologic and water quality modeling In *Agricultural Nonpoint Source Pollution: Model Selection and Application.* ed A Giorgini and F Zingales, pp 345-362

Dillaha, T A III, D B Beasley, and L F Huggins 1982 Using the ANSWERS model to estimate sediment yields on construction sites *Journal of Soil and Water Conservation* 37(2) 117-120

Dillaha, T A , C D Heatwole, M R Bennett, S Mostaghimi, V O Shanholtz, and B B Ross 1988 *Water quality modeling for nonpoint source pollution control planning Nutrient transport.* Virginia Polytechnic Institute and State University, Dept of Agricultural Engineering Report No SW-88-02

Donigian, A S , Jr , and W C Huber 1991 *Modeling of nonpoint source water quality in urban and non-urban areas.* Environmental Protection Agency, Environmental Research Laboratory, Athens, Georgia EPA/600/3-91/039

Freedmann, P L and D W Dilks 1991 Model capabilities - A user focus In *EPA Workshop on the Water Quality-based Approach for Point Source and Nonpoint Source Controls*, June 1991 pp 26-28. EPA 503/9-92-001

DR3M-QUAL: Distributed Routing Rainfall Runoff Model - Quality

1. Distributor:

Ms Kate Flynn
410 National Center
U S Geological Survey
Reston, VA 22092
(703) 648-5313

2 Type of Modeling

- Urban stormwater pollutant loads
- Continuous simulation
- Continuous, intermittent, and diffuse source/release
- Intermediate and detailed applications

3 Model Components

- Rainfall/runoff assessment
- Water quality analysis

4. Method/Techniques:

This model simulates rainfall/runoff processes (hydrographs) and water quality processes (pollutographs) in urban and other areas The kinematic wave method is used over multiple subcatchments to predict runoff from rainfall and drainage pathways A built-in optimization routine and a storage-indication routine are available for estimating water quantity parameters Exponential build-up and wash-off functions derived from experience with model calibration are applied to predict water quality Empirical equations use relationships between sediment yield and runoff volume and peak to simulate erosion The erosion parameters are selected based on the USLE The transport process is modeled assuming plug flow and using a Lagrangian scheme. Calibration is required for accurate quality predictions However, default values may be used for screening level analysis

7. Applications

- Rainfall/runoff assessment
- Surface water quality analysis

6. Number of Pollutants:

- Sediment, nitrogen, and phosphorus, metals, and organics

7. Limitations.

- No interaction among quality parameters
- Sediment transport simulation is weak

8 Experience.

The program has been extensively reviewed within the USGS and applied to several urban modeling studies, including South Florida (1980), Rochester (1985 and 1988), Anchorage (1986), Denver (1987), and Fresno (1988)

9. Updating Version.

N/A

10. Input Data Requirements·

- Subcatchment data area, imperviousness, length, slope, roughness, and infiltration parameters

- Trapezoidal or circular channel dimensions and kinematic wave parameters
- Stage-area-discharge relationships for storage basins
- Water quality parameters, including build-up and wash-off coefficients

13. Simulation Output:

- Time series of runoff hydrographs and quality pollutographs (concentration or load vs. time) at any location in the drainage system
- Summaries for storm events
- Graphical output of water quality and quantity analysis

14. References Available

Alley, W.M. 1981 Estimation of impervious-area wash-off parameters *Water Resources Research* 17(4) 1161-1166.

Alley, W.M. 1986 Summary of experience with the distributed routing rainfall-runoff model (DR3M) In *Urban Drainage Modeling* ed C Maksimovic and M. Radojkovic pp 403-415 Pergamon Press, New York

Alley, W.M. and P E. Smith 1981 Estimation of accumulation parameters for urban runoff quality modeling *Water Resources Research* 17(6) 1657-1664

Alley, W.M. and P E Smith 1982a *Distributed Routing Rainfall-Runoff Model - Version II*. U.S. Geological Survey, Reston, VA. Open file report 82-344

Alley, W.M and P.E. Smith 1982b *Multi-event urban runoff quality model.* U.S. Geological Survey Reston, VA Open file report 82-764,

Brabets, T P 1987 *Quantity and quality of urban runoff from the Chester Creek basin Anchorage, Alaska.* U S Geological Survey, Anchorage, AL Water-Resources Investigations Report 86-4312

Donigian, A S , Jr , and W C Huber 1991 *Modeling of nonpoint source water quality in urban and non-urban areas* U S Environmental Protection Agency, Environmental Research Laboratory, Athens, Georgia EPA/600/3-91/039

Guay, J R and P E Smith 1988 *Simulation of quantity and quality of storm runoff for urban catchments in Fresno, California.* U S Geological Survey, Sacramento, CA USGS Water-Resources Investigations Report 88-4125,

Kappel, W M , Yager, R M and P J Zarriello 1986 *Quantity and Quality of Urban Storm Runoff in the Irondequoit Creek Basin near Rochester, New York, Part 2 Quality of Storm Runoff and Atmospheric Deposition, Rainfall-Runoff-Quality Modeling, and Potential of Wetlands for Sediment and Nutrient Retention* U S Geological Survey, Ithaca, NY USGS Water-Resources Investigations Report 85-4113

Lindner-Lunsford, J B and S R Ellis 1987 *Comparison of Conceptually Based and Regression Rainfall-Runoff Models, Denver Metropolitan Area, Colorado, and Potential Applications in Urban Areas.* U S Geological Survey, Denver, CO USGS Water-Resources Investigations Report 87-4104,

Zarriello, P J 1988 Simulated water-quality changes in detention basins In *Design of Urban Runoff Quality Controls.* ed L A Roesner, B Urbonas, and M B Sonnen Proceedings of Engineering Foundation Conferences, Potosi, MI. ASCE, New York pp 268-277

SWRRB: Simulation for Water Resources in Rural Basins

1. Name of Distributor.

Dr Jimmy R Williams
Agriculture Research Service
U S Department of Agriculture
Grassland, Soil and Water Research Lab
Temple, TX 76502
(817) 770-6502

2 Type of Modeling

- Stormwater from agricultural watersheds
- Diffuse source/release
- Screening, intermediate, and detailed applications

3 Model Components

- Rainfall/runoff assessment
- Surface water quality analysis
- Soil/groundwater contamination

4 Method/Techniques

This program evaluates basin-scale (large, complex, and rural basins) water quality Surface runoff is described by the SCS curve number equation The modified Universal Soil Loss Equation (USLE) is applied to simulate erosion for each basin Degradation and deposition are considered for the channel and floodplain sediment routing model Bagnold's stream power concept is used for degradation processes, while the fall velocity of sediment particles is used for deposition Return flow, percolation, and crop growth are calculated Soluble and sediment-attached pollutants are considered for pollutant transport Nutrients (nitrogen and phosphorus) are simulated by using relationships between chemical concentration, sediment yield, and runoff volume Calibration is not specifically required but is desirable

5. Applications

- Water and sediment yields from ungaged rural basins
- Return flow, pond and reservoir storage, and crop growth
- Sediment movement through ponds, reservoirs, streams, and valleys
- Flood routing

6. Number of Pollutants.

Sediment components, nitrogen, phosphorus, and pesticides

7 Limitations:

- Nutrient transformations are not evaluated

8 Experience:

The model was tested on 11 large watersheds The testing results showed that SWRRB can simulate water and sediment yield under a wide range of soils, climate, land use, topography, and management systems

9 Updating Version

N/A

10. Input Data Requirements·

- Meteorological data (daily precipitation and solar radiation)
- Soils, land use, and fertilizer and pesticide application

11. Simulation Output.

- Daily runoff volume and peak rate, sediment yield, evapotranspiration, percolation, return flow, and pesticide concentration in both runoff and sediment
- Nutrient concentrations/loads

12. References Available:

Arnold, J.G., J.R Williams, A D Nicks, and N.B. Sammons 1989 *SWRRB, a basin scale simulation model for soil and water resources management* Texas A&M Press.

Arnold, J G., and J.R Williams 1987 Validation of SWRRB - simulator for water resources in rural basins *Journal of Water Resources Planning and Management* 113(2) 243-256

Computer Science Corporation. 1980 *Pesticide runoff simulator user's manual.* U S Environmental Protection Agency, Office of Pesticides and Toxic Substances, Washington, DC

Donigian, A S , Jr , and W C Huber 1991 *Modeling of nonpoint source water quality in urban and non-urban areas* U S Environmental Protection Agency, Environmental Research Laboratory, Athens, Georgia EPA/600/3-91/039

Williams, J R ,and H D Berndt 1977 Sediment yield prediction based on watershed hydrology *Transactions of the ASAE* 20(6) 1100-1104

Williams, J R , A D Nicks, and J G Arnold 1985 Simulator for water resources in rural basins *Journal of Hydraulic Engineering ASCE* 111(6) 970-986

SWMM: Storm Water Management Model

1 Name of Distributor

Mr. David Disney
U S Environmental Protection Agency
Environmental Research Laboratory
College Station Road
Athens, GA 30613
(404) 546-3123

2 Type of Modeling

- Urban stormwater processes
- Continuous and storm event simulation with variable and user-specified time steps (wet and dry weather periods)
- Single, continuous, intermittent, multiple, and diffuse source/release
- Screening, intermediate, and detailed planing applications
- Evaluation of BMPs and development of design criteria

3 Model Components

- Rainfall/runoff assessment
- Water quality analysis
- Soil/groundwater contamination
- Point source inputs available

4 Method/Techniques

This model simulates overland water quantity and quality produced by storms in urban watersheds. Several modules or blocks are included to model a wide range of quality and quantity watershed processes A distributed parameter sub-model (RUNOFF) describes runoff based on the concept of surface storage balance The rainfall/runoff simulation is accomplished by the non-linear reservoir approach The lumped storage scheme is applied for soil/groundwater modeling For impervious areas, a linear formulation is used to compute daily/hourly increases in particle accumulation For pervious areas, a modified Universal Soil Loss Equation (USLE) determines sediment load The concept of potency factors is applied to simulate pollutants other than sediment.

5 Applications

- Urban stormwater and combined systems
- Surface water routing
- Urban watershed analysis, including baseflow contributions

6 Number of Pollutants

Limited to ten pollutants, including sediment

7 Limitations.

- Lacks graphics routines
- Quality and solids transport simulations are weak

8. Experience:

Applied to urban hydrologic quantity/quality problems in over 100 locations in the United States and Canada

9 Updating Version:

Version 4 04 (1989)

10. Input Data Requirements

- Rainfall hyetographs, antecedent conditions, land use, and topography
- Dry-weather flow and soil characteristics
- Gutter/pipes - hydraulic inputs
- Pollutant accumulation and wash-off parameters
- Hydraulics and kinetic parameters

11. Simulation Output:

- Time series of flow, stage, and constituent concentration at any point in watershed
- Seasonal and annual summaries

12. References Available

Cunningham, B A and W C Huber 1987. *Economic and predictive reliability implications of stormwater design methodologies*. Florida Water Resources Research Center, University of Florida, Gainesville, FL Publication No 98

Dever, R J., Jr , L A Roesner, and J A Aldrich. 1983 *Urban highway storm drainage model vol. 4, Surface runoff program user' manual and documentation.* Federal Highway Administration, Washington, DC FHWA/RD-83/044.

Dever, R J , Jr , L A Roesner, and D-C , Woo 1981 Development and application of a dynamic urban highway drainage model In *Urban Stormwater Hydraulics and Hydrology, Proceedings of the Second International Conference on Urban Storm Drainage*, Urbana, IL pp 229-235 Water Resources Publications, Littleton, CO

Donigian, A S , Jr , and W C Huber 1991 *Modeling of nonpoint source water quality in urban and non-urban areas* U S Environmental Protection Agency, Environmental Research Laboratory, Athens, Georgia EPA/600/3-91/039

Huber, W C 1986 Deterministic Modeling of Urban Runoff Quality In *Urban runoff pollution, Proceedings of the NATO Advanced Research Workshop on Urban Runoff Pollution*, Montpellier, France ed H C Torno, J Marsalek, and M Desbordes pp 167-242 Series G Ecological Sciences Vol 10 Springer-Verlag, New York

Huber, W C 1989 User feedback on public domain software SWMM case study In *Proceedings of the Sixth Conference on Computing in Civil Engineering,* Atlanta, Georgia American Society of Civil Engineers, New York, NY

Huber, W C and R E Dickinson 1988 *Storm Water Management Model Version 4, User's manual* U S Environmental Protection Agency, Athens, GA EPA600/3-88/001a (NTIS PB88-236641/AS)

HSPF: Hydrological Simulation Program - FORTRAN

1. Distributor·

Mr David Disney
U S Environmental Protection Agency
Environmental Research Laboratory
College Station Road
Athens, GA 30613
(404) 546-3123

2. Type of Modeling

- Pollutant load and water quality in complex watersheds
- Continuous and storm event simulation
- Single, continuous, intermittent, multiple, and diffuse source/release
- Screening, intermediate, and detailed applications
- BMP evaluation and design criteria

3 Model Components:

- Watershed hydrology assessment
- Surface water quality analysis (conventional and toxic organic pollutants)
- Soil/groundwater contaminant runoff processes with instream hydraulic and sediment-chemical interactions (saturated and unsaturated zones)
- Pollutant decay and transformation

4. Method/Techniques.

This model calculates surface and subsurface pollutant transport from complex watersheds to receiving waters Hydrolysis, oxidation, photolysis, biodegradation, volatilization, and sorption are used to describe the transfer and reaction processes First-order kinetic processes are employed to model sorption Water quality is simulated by a lumped parameter model Three sediment types (sand, silt, and clay) and a single organic chemical as well as transformation products of that chemical can be simulated The program can assess the water quality impacts of alternative best management practices (BMPs) Calibration is required for model application Because of the modular approach, detail of application can be varied depending on data availability and modeling needs

5 Applications

- Surface and subsurface pollutant transport to receiving water with subsequent simulation of instream transport and transformations
- Watershed hydrology and water quality for both conventional and toxic organic pollutants
- Evaluation of BMPs and development of design criteria

6 Number of Pollutants

Seven pollutants three sediment components (sand, silt, and clay), one pesticide or other toxic pollutant (user-specified), BOD, ammonia or nitrate, and orthophosphate

7 Limitations

- Limited to well-mixed rivers and reservoirs
- Extensive water quality sampling data required for calibration or verification

- Highly trained staff required for model application

8. Experience:

- Developed based on field data gathering and testing at an Iowa site
- Recently used to model erosion and BMP effects on a west Tennessee watershed with calibration and verification
- Extensively applied in a wide variety of hydrologic and water quality studies

9. Updating Version:

Version 9.01, 1989

10. Input Data Requirements:

- Continuous rainfall records
- Continuous records of evapotranspiration, temperature, and solar intensity
- A large number of parameters need to be specified (some default values are available)

11. Simulation Output.

- Time series of the runoff flow rate, sediment load, and nutrient and pesticide concentrations
- Time series of water quantity and quality at any point in a watershed
- Frequency and duration analysis routine

12. References Available.

Barnwell, T O., and R Johanson 1981 HSPF: A comprehensive package for simulation of watershed hydrology and water quality. In *Nonpoint pollution control: tools and techniques for the future.* Interstate Commission on the Potomac River Basin, Rockville, MD

Barnwell, T O ,and J L Kittle 1984 Hydrologic Simulation Program - FORTRAN Development, maintenance and application In *Proceedings Third International Conference on Urban Storm Drainage.* Chalmers Institute of Technology, Goteborg, Sweden

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