V. MODEL EVALUATION PROCESS

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A two step evaluation process was developed to assess model capabilities and accuracy of basin-scale models. The objective of the model evaluation was designed to provide a comprehensive side-by-side comparison of basin-scale models and their respective role in FQPA drinking exposure assessments.

The first step of the evaluation process was patterned from previous model evaluations conducted by the Environmental Modeling Work Group (EMWG) and Quick-Response Task 2 Fate and Transport Model Comparisons (EPA Contract No. 68-W6-0053). Additionally, several model developers were surveyed by EFED scientists to expedite the model evaluation process. Although the questionnaire was designed to provide Yes or No answers, the model developers were encouraged to elaborate on specific model capabilities. In fact, several model capabilities required write-in answers. Upon completion of the evaluation, model developers were contacted for clarification on specific technical issues and correctness.

As a second step, a preliminary validation process is planned to establish the accuracy of the basin-scale models in predicting pesticide concentrations in a flowing water body within a watershed. OPP has consulted with USGS on suitable NAWQA monitoring sites for model validation. As a result of this collaboration, the Kessinger Ditch and Sugar Creek watersheds in the White River Basin in Indiana were selected as potential watersheds for the purpose of model validation (Background Document #4).

The evaluation was conducted on the following basin scale models: surface water regression models, conceptual flowing water and reservoir screening model, modified linkage of Pesticide Root Zone Model (PRZM)- EXposure Analysis Modeling System (EXAMS), Waterborne Environmental, Inc. RIVer Water Quality (RIVWQ), USEPA Better Assessment Science Integrating Point and Non-Point Sources (BASINS), USDA Soil Water Assessment Tool (SWAT), USDA Annual Agricultural Non-Point Source (Annual AGNPS). A written evaluation for each model or modeling approach is shown below.

SCREENING LEVEL MODELS

Surface Water Regression Models

The development of a surface water regression screening model was a common recommendation from individual panel members on the 1997 FIFRA SAP and ILSI panels. These recommendations have fostered exploratory research to establish mathematical or statistical relationships between environmental factors, pesticide fate properties, and use rate to pesticide concentrations in streams or rivers. These mathematical relationships may be used as a predictive tool for estimating pesticide concentrations in surface waters.

The American Crop Protection Association (ACPA) has developed a preliminary watershed scale surface water regression screening model. The model, SWMII, has been presented to OPP as an example of a modeling approach (Background Document #5). The model developers claim that SWMII cannot be implemented without additional development and testing. OPP has conducted an independent assessment of SWMII (version 1)(Background Document # 6).

Additionally, OPP is working with USGS to establish relationships between pesticide monitoring data and pesticide usage data, hydrology, pesticide fate properties, and climatic conditions for several tributaries in the White River Basin. This research may yield predictable relationships, which can be used to develop regression type models. Also, this research effort will complement basin-scale model validation proposed as part of the basin-scale model evaluation process.

References

Chen, W., P. Hertl, S. Chen, and D. Tierney. 1998. A Simple Regression Model for Predicting Surface Water Concentration Resulting from Agricultural Field Runoff and Erosion. American Crop Protection Association.

Conceptual Flowing Water with Reservoir Screening Model (CFWRM)

A conceptual flowing water and reservoir screening model was presented to the FIFRA SAP in December, 1997 (Background Document # 7). A description of the algorithms of the CFWRM is attached. The SAP concluded that the proposed CFWRM could be used as a screening level model because the conceptual model has the potential to predict more accurate but conservative pesticide concentrations in drinking water when compared to the GENEEC screening model. Additionally, the SAP panel members recommended that alternative screening models may be developed from either meta-models of mechanistic basin scale models or surface water regression models.

The CFWRM was designed to simulate a watershed through the use of multiple fields along a river connected to a reservoir. Pesticide loading from runoff and spray drift would be simulated using similar algorithms as the GENEEC model. Pesticide loading events would be determined by application timing. First-order aerobic soil metabolism and linear sorption (K_{oc}) on soil are simulated according algorithms in the GENEEC model. Once the pesticide is loaded into river, the model assumes that the pesticide is evenly distributed with depth within each node of the river adjoining a simulated field under steady-state runoff into a well mixed, steady-state inflow/outflow reservoir. In the river and reservoir, lumped first-order degradation in the dissolved phase including biodegradation, hydrolysis, photodegradation and linear sediment sorption are simulated. Mass balance of sediment sorbed pesticides is considered to be disconnected from dissolved pesticide concentrations in the river and reservoir as in the GENEEC model.

SURFACE WATER ROUTING MODELS

Modified linkage of Pesticide Root Zone Model (PRZM)- EXposure Analysis Modeling System (EXAMS)

OPP and ORD are working on a joint project to modify the PRZM/EXAMS linkage to simulate a watershed/river/reservoir drinking water supply system. This will be accomplished by developing a data base consisting of the major crops (1992 Agricultural Census, U.S. Department of Commerce; 1992 Natural Resources Inventory, U.S. Department of Agriculture), soil types (State Soil Geographic Database, U.S. Department of Agriculture) and aquifer materials (Regional Aquifer System Analysis, U.S. Geological Survey) for the watersheds in the U.S. with vulnerable (likely to be impacted from agricultural activities) drinking water utilities (under development). Scenarios for the watersheds will be constructed and used as input into PRZM. The scenario for a specific watershed would then be subdivided into smaller scenarios with similar hydro geologic and soil characteristics. PRZM would be used to determine the pesticide concentration in runoff and leachate from each subdivided scenario. The runoff pesticide concentrations would then be simultaneously input into EXAMS. The input from each PRZM run would be associated with a separate reach segment of a stream or river feeding into a reservoir or segment discharging directly into the reservoir. The EEC's would then be determined for the pesticide in the stream or reservoir at different times after the application of the pesticide to the cropped area. This approach will be based on steady-state flows for the source water; volume per day for the stream and volume for the reservoir. When drinking water is supplied by surface and groundwater, the EEC contribution from groundwater will be determined by using the pesticide concentration in the leachate determined from PRZM and then approximating the travel time to the discharge point for the groundwater from the hydrogeologic characteristics of the aquifer material. Degradation and adsorption processes will be considered during the residence time in the aquifer. This will constitute another input into EXAMS.

PRZM will have to be changed to include the groundwater contribution to EXAMS from leachate. EXAMS will have to be changed so that it can accept PRZM inputs from multiple scenarios simultaneously. Also, a reservoir component will have to be added. Watershed scenarios will have to be developed for input into PRZM.

OPP has determined the location of all the public drinking water utilities (PDWU) for populations greater than 5000 and for a small percentage (to be determined after data cleaning) for those serving less than 5000; source: Safe Drinking Water Information System (SDWIS). We are in the process of doing a QA/QC on this data set which involves a manual review of the download due to a lack of automated filters on parameter codes. The location of the PDWUs will be correlated (linked) with stream reaches and reservoir locations on a basin-scale level (accounting or cataloging unit) after the QA/QC. This "link" will provide specific geomorphological information on the drinking water utility's source water (e.g., basin size and flow).

Waterborne Environmental, Inc. RIVer Water Quality (RIVWQ)

I. Introduction

RIVWQ (Chemical Transport Model for Riverine Environments) was developed by Waterborne Environmental, Inc. to evaluate the transport of organic chemicals in a tributary riverine system. It was developed based on the algorithms from the dynamic salt transport simulation model, SWIM (Salt-Water Intrusion Model) and the lake water-quality model contained within SWRRB-WQ (Simulator for Water Resources in Rural Basins - Water Quality).

RIVWQ was written to be compatible with the pesticide runoff models of PRZM, RICEWQ and GLEAMS, which operate on a daily time step. It was designed mainly as a water routing model which accepts and processes water and chemical inputs from other field scale models to simulate the riverine system within a watershed.

II. Model Operation

RIVWQ is a continuous time model that operates on a daily time step. The objective of the model is to predict the water quality impact of tributary point-sources and agricultural non-point sources to the watershed.

The code is developed with FORTRAN 90 and mainly in PC DOS platform. It can also be implement in the DOS shell of Windows 95 and Windows NT.

To facilitate the model operations, Waterborne has developed pre-processors for linkage with PRZM, RICEWQ, and GLEAMS, and bulk file processing of multiple RIVWQ simulations. Waterborne also developed post-processors for output data reduction and statistical processing. All these processing tools and the model itself are available at certain fees. The modeling support by the developers is free if under an undefined deadline. Otherwise, the charge is under corporate fee structure.

III. Model Component

RIVWQ is a water routing model in nature. The system geometry used in RIVWQ is represented using a line-note approach in which the prototype is divided into a number of discrete volumes (nodes or junctions) connected by flow channel (links). This approach is similar to several well-known water quality models, including QUAL-2 and WASP-5. RIVWQ can accommodate tributaries, but not network or looped environments. RIVWQ does not simulate flow reversals, backwater conditions, or other unsteady flow phenomena.

Model simulation involves mathematically tracking the total mass of chemical residues in the tributary system from the loading point in terms of mass balance. Chemical residues in water are assumed to be instantaneously diluted in each control volume (node). Dynamic constituent transport occurs between nodes via links and is a balance between river-driven flows and

dispersion processes. Chemical transformations occur within nodes and can include dilution, volatilization, partitioning between water and bed sediments, decay in water and sediment, and resuspension from bed sediments.

IV. Model Inputs and Outputs

All the input and output file names are "hard-wired" in the RIVWQ. The users are advised to change and save the input and output file names after each RIVWQ run. This can be accomplished using the command batch file in the RIVWQ model package.

Inputs - RIVWQ operates up to five input files (with the naming of RIVWQ followed by extensions of .INP, .CON, .HYD, .HY2, and .MAS) depending on the user's need: (1) .INP file describing basic input data including simulation control, system definition and geometry and initial conditions; (2) .CON file containing boundary condition concentrations; (3) .HYD file containing streamflow records; (4) .HY2 file containing paddy water, outflow and drainage information; and (5) .MAS file containing chemical mass loadings.

Outputs - RIVWQ generates three output files (with the naming of RIVWQ followed by extensions of .ZZ1, .ZZ2, and .ZZ3). (1) .ZZ1 file containing an echo of input data. This file serves the purpose for double checking to ensure that input parameters are entered correctly. (2) .ZZ2 file containing time histories at points of interest, and (3) .ZZ3 file containing daily snap shots of the system.

V. Model Application

In 1997, a subcommittee of the FIFRA Exposure Modeling Work Group developed a tentative tiered process to address drinking water exposure under the Food Quality Protection Act (FQPA). The tiers were designed to be somewhat analogous to the process currently used for ecological risk assessment, starting with a quick assessment tool similar to GENEEC for Tier 1; standardized watershed scenarios in contrast to "standard pond" scenario for Tier 2; limited strategic monitoring for Tier 3; and more comprehensive monitoring for Tier 4.

The PRZM-RIVWQ linkage was demonstrated as a conceptual model for a Tier-2 level assessment for FQPA. A hypothetical but realistic watershed was presented that contained mixed land use and variable chemical application dates. A 20 mi^2 watershed containing a reservoir with a relatively long hydraulic residence time was simulated as being representative of a vulnerable drinking water supply system. Drinking water exposure concentrations, based on a continuous simulation of 36 years of weather data, were reported for both flowing water (river) and reservoir components of the watershed.

PRZM-3 was used in the simulation because it is the primary model used for FIFRA regulatory purposes, because it is under active development and improvement, and because it is receiving

extensive evaluation by the FIFRA Environmental Model Validation Task Force (FEMVTF). RIVWQ was used to represent chemical fate and transport in the receiving water system because it has the ability to simulate relevant governing processes at an appropriate time-step and scale, because it has existing linkages with PRZM, and because it was time- and cost-efficient to set up for demonstration purposes.

The developers envisioned a series of watershed scenarios that would reflect regional variability in soil, weather, and crop/land use characteristics (36 such watershed models have been developed to date). The scenarios could be operated under a shell similar to MUSCRAT with the potential of being compatible with soil-weather combinations within MUSCRAT. The developers envisioned incorporating additional landscape features into the model, such as subsurface flow, drain tile, and buffer zones. These features are under various stages of development by Waterborne.

VI. Model Validation

RIVWQ is presently being validated on several systems varying form 10 to 100 square miles. Due to the confidentiality of data nature, the publications are pending upon the approval of sponsors.

VII. Critical Assessment

Strength of Model - RIVWQ is easy to use, relatively stable, and configured for statistical calculations of exposure concentrations through multiple runs and batch job processing. It is developed to fill a need between more simplistic and sophisticated modeling approaches.

- RIVWQ was specifically designed to address a Tier 2/Tier 3 level-of -effort risk assessment. The model fills a need between more simplistic and more sophisticated approaches.
- Data requirements, user learning curve, computer hardware (memory, speed, and disk storage) is minimal compared to other approaches being considered.
- The standardized watershed presented by the developers is analogous to procedures used for ecological risk assessments, but adjusted to reflect additional factors relevant for drinking water end points.
- The scale used in the demonstration addresses highly vulnerable environments, likely to be neglected by larger basin approaches.
- The tool is available for immediate implementation. If nothing else, it can be used as an interim assessment tool while other procedures are under development.

- Additional scenarios could be configured readily by characterizing crop/soil/land use variability by NRI sample points at the HUC-8/MLRA/county polygon scale. The developers are willing to conduct this analysis.

- The approach uses object-oriented (modular) technology in that PRZM or RIVWQ can be replaced with newer versions of these models or other models as technology improves.

Weaknesses of Model - Degradation is represented by lumped 1st-order kinetics. Distinct biological and chemical transformation processes are not included. Degradation products are currently not simulated. Suspended sediment is held constant in a link or as a function of discharge as specified in a user applied rating curve. Unsteady flow hydrodynamics are not represented.

- RIVWQ does not currently reside within the public domain. However, the authors appear receptive to placing the model within EPA's CEAM library.

- Currently, the model does not have a large user base. Additional model review and testing is recommended.

References

Williams, W. M., C. E. Zdinak, A. M. Ritter, and J. P. Cheplick. 1997. RIVWQ: Chemical Transport Model for Riverine Environments: Users Manual and Program Documentation Version 1.41 (Seriel #002-141-0001. Waterborne Environmental, Inc., Leesburg, VA.

USEPA Better Assessment Science Integrating Point and Non-Point Sources (BASINS)

I. Introduction

The Hydrologic Simulation Program - FORTRAN (HSPF) has been added as a module to the Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) model. However, HSPF as implemented in BASINS does not have all the capabilities that the HSPF model operating independently possesses. The HSPF module in BASINS, which is named the Nonpoint Source Model (NPSM), has several useful features that enhance the utility of HSPF.

HSPF is a comprehensive, continuous watershed simulation model designed to simulate the water quality and water quality processes that occur in a watershed, including sediment transport and movement of contaminants like pesticides. Although classified as a lumped model, HSPF can reproduce spatial variability by dividing the basin into hydrologically homogeneous land segments and simulating runoff for each land section using different input data and watershed parameters.

BASINS is an integrated GIS, data analysis, and modeling system that is designed to support watershed based analysis and total maximum daily load development. The US EPA's Office of Science and Technology within the Office of Water developed BASINS as tool to facilitate examination of environmental information, to provide an integrated watershed and modeling framework, and to support analysis of point and nonpoint source management alternatives.

BASINS contains a suite of interrelated components essential for performing watershed and water quality analysis. These components are grouped into three categories--national databases with local data import tools, assessment tools, and watershed and water quality models including the NPSM, or the modified HSPF model. BASINS' databases and assessment tools are integrated within an ArcView 3.0a GIS environment. These features coupled with the HSPF model provide a powerful tool for evaluating water quality component within a selected watershed.

> **History**-HSPF evolved from the Stanford Watershed Model developed by Crawford and Linsley (1966). This model was one of the first comprehensive watershed models, and it has undergone numerous modifications and additions during the past 30 years. Crawford and Linsley further developed the original model and created HSP, the Hydrocomp Simulation Program, which included sediment transport and water quality simulation. In the 1970's, Hydrocomp developed the Agricultural Runoff and Management Model (ARM) and the Nonpoint Source Pollution Loading Model (NPS) for the US EPA.

Because of limitations in these existing simulation models, especially in terms of data management and compatibility with other models, the US EPA commissioned Hydrocomp, Inc. to develop a system of simulation modules in FORTRAN that would handle the functions of HSP, ARM, and NPS. The result was HSPF that could simulate hydrologic and associated water quality processes on pervious and impervious surfaces and in streams and well-mixed impoundments. Several revisions in the HSPF model have been developed. The most recent version of HSPF is version 11, which was released in April 1997. Currently, the US EPA and the US Geological Survey provide funding for maintenance and development of HSPF.

Features-NPSM module within the BASINS model utilizes GIS procedures and a Windows 95 interface to run the modified HSPF model. NPSM provides a windows interface with three main modules, PERLND, IMPLND, and RCHRES and to the input and output files that are generated. PERLND simulates all pervious land activities and computes runoff and pollutant (pesticide) loads. IMPLND simulates all impervious land activities and computes runoff and pollutant (pesticide) loads. RCHRES simulates both routing of flows and water quality behavior through a connected network of reaches, which could include streams, rivers, lakes, and reservoirs.

NPSM has additional features which enhances the capabilities of the HSPF model. NPSM creates an HSPF input file that can simulate both point and nonpoint source contributions for an area of interest. This is a simplified implementation in that only a single value of flow and pollution concentration (based upon a NPDES permit data) can be specified. This steady-state simulation procedure within NPSM will eventually be supplemented with time varying flows and pollutant concentration techniques. Another useful feature with this model is the watershed delineation tool, which allows the user to delineate a sub-watershed from within an 8-digit catalog unit. The GIS capabilities with this model permits a great deal of flexibility in using exiting databases, modifying databases, and/or creating your own database.

II. Model Components

The major modeling components in HSPF and NPSM that impact pesticide fate and transport in surface waters are hydrology, weather, soils, land use, pesticides, sediments, overland flow and, overland water quality, stream and reservoir routing, water quality simulation, and model inputs and outputs.

Hydrology-The hydrologic modeling components include precipitation (rainfall or snow), irrigation, interception, depression storage, evapotranspiration, infiltration, surface storage, runoff, interflow, and ground-water flow. HSPF uses a water balance equation which utilizes the previously mentioned hydrologic modeling components, rainfall-runoff relationships, storm characteristics (areal distribution and duration, intensity, and magnitude of rainfall), and snow melt to estimate runoff.

Weather-All three computation modules--PERLND, IMPLND, and RCHRES require extensive weather data. The weather parameters that are required by these modules are precipitation (rainfall and snow), evaporation, potential evapotranspiration, air temperature, wind speed, solar radiation, dewpoint temperature, and cloud cover. These weather parameters are used in the water balance equations and parameters, which are contained within the three computation modules. The weather data are time series, that is hourly, data, etc.; however, within HSPF the recommended time interval for nonpoint modeling is hourly. The BASINS model permits large sets of weather data to be efficiently managed by Watershed Data Management (WDM) file. The BASINS model has several existing WDM files, and BASINS also permits user supplied weather files and modifications in the weather files.

Soils-STATSCO soil files are used to provide soil series delineation within multiple watersheds, a watershed, or sub-watershed. These files also provide soil parameters which are used in determining runoff and infiltration of precipitation and irrigation waters. BASINS with its Arc/View GIS capabilities to read and manipulate soils data provides important hydrologic capabilities to the HSPF model.

Land Use-BASINS provides GIS land use coverages for the United States, and other sources of GIS land use files are available at different levels of detail. Land uses for pervious and impervious land types are selected, and the HSPF model uses different land use algorithms to compute the hydrologic features for each of these land types.

Crop Growth Parameters and Agriculture Management Procedures-HSPF and NPSM within BASINS do not have crop growth parameters like biomass production, ground cover, leaf area index, root growth, rooting depths, and crop yields. These models also lack agricultural management procedures like irrigation types, tillage practices, buffer strips, grassed waterways, terraces, and tile drains. The NPSM model can simulate some of these agricultural management procedures through creative operations of this program. However, a better approach would be to add these parameters and procedures to these models.

Pesticides-A variety of pesticide procedures can be handled by these models. All types of pesticides like organic, inorganic, hydrophobic, and hydrophilic and their transformation products can be simulated with one or multiple applications per year. Pesticide application procedures like broadcast, foliar, soil incorporation, and chemigation are also handled by these models.

The HSPF and NPSM models are capable of simulating within the soils pesticide degradation, adsorption/desorption, and transport to surface water, interflow or lateral flow, and ground water. The pesticide degradation, adsorption/desorption, and transport procedures occur to varying degrees in the root, vadose, and ground-water zones. The adsorption/desorption procedures are first order kinetics with either single or non-single

value Freundlich isotherms. However, these models have not been developed to handle foliar interception, washoff, or degradation; plant uptake; and spray drift.

Overland Flow-Factors that impact overland flow or runoff are rainfall; snow melt; interception, which includes the moisture retained by ground cover and depression storage and losses by evaporation; infiltration; evapotranspiration; soils; and land use. The amount of overland flow is calculated using the water balance equation and rainfall-runoff relationships. The algorithms for computing overland flow are available for both pervious and impervious lands within each watershed.

Overland Water Quality-Overland water quality, the water quality of surface runoff, is dependent upon the land uses within the watershed and the physical characteristics of the watershed. Because urban landscapes have more impervious areas than rural landscapes, there are differences in the pollutants or pesticides that develop from an urban or rural landscapes. HSPF and the NPSM module in the BASINS model will simulate the overland water quality that develops from these different landscapes.

Sediments-The sediment procedures are common to both the PERLND and IMPLND modules, and sediment delivery algorithms that compute the amount of sediments eroded from a field and delivered to a watershed outlet are available in both these modules. The major components of the sediment modules include sediment or soil build up, detachment, transport, and scouring. The erosion calculation is based upon the Universal Soil Loss Equation. The erosion processes includes sediment carrying capacity of the flow, runoff energy, and adsorption/desorption of dissolved pesticides and other pollutants.

Hydraulic (Stream) Routing-The transport of surface waters in rivers and streams is simulated in the HYDR module. The major components of this module are single layer flow which is completely mixed, unidirectional flow, flow routing by the kinematic wave or storage-routing method where the conservation of momentum is not considered, function tables for the depth-volume-discharge relationship for each reach, the use of precipitation and evaporation data, and the calculation of outflow, depth, volume, surface area, and selected additional variables. Inflow parameters are tributaries, point sources, and nonpoint source flows. The BASINS implementation features flows generated for each reach, capabilities to delineate sub-watersheds, and final flows and loads calculated at the most downstream reach in the watershed.

Water Quality Simulation -The water quality simulation evaluates the instream processes like advective flow of dissolved materials and sediments; the movement of conservative constituents; impacts of water temperature on radiation flow, convection, evaporation, and precipitation; degradation processes, and the impact of degradants within the surface water system. The degradation processes evaluated are hydrolysis, photolysis, oxidation, volatilization, and biodegradation.

Model Inputs and Outputs -The NPSM module operating within BASINS streamlines

and simplifies the HSPF data input procedures. (The HSPF model allows changing values of 500-1000 input parameters.) The BASINS model incorporates GIS techniques and a variety of useful GIS coverages which enhances and simplifies usage of the HSPF model.

The output procedures within the NPSM module simplify and increase the utility of the HSPF. In addition the post-processor procedures within NPSM make it is easier to compare HSPF runs and to incorporate both monitoring data and statistical techniques for evaluating model results.

III. Model Validation

The evolution of the HSPF (and the development of NPSM its interface within BASINS) has resulted in publication of several HSPF validation studies. HSPF model validations were performed by Beyerlein and Brasher (1993), Chen, et al. (1995), and Chen, et al (1996).

IV. Model Applications

A variety a HSPF model applications have been performed over the past several years. A few selected examples of these HSPF application are the following: Donigan Jr. and Crawford (1976), Donigan Jr., Imhoff, and Bicknell (1983), and Hess (1996).

V. Model Availability

HSPF NPSM is available as a module within the BASINS model, which has been implemented within a PC environment that operates under Windows 95. The model is public domain. The BASINS model is available through the US EPA's Office of Science and Technology within the Office of Water. It is also available through the Internet at http://www.epa.gov/ost/BASINS.

VI. Advantages and Disadvantages

There are several advantages to using the NPSM module within BASINS to simulate the impact of field applications of pesticides on stream water quality within a watershed to basin size areas. The linkage of BASINS to GIS procedures and coverages enhances the utility of the HSPF procedures. BASINS also contains a suite of watershed tools--Target, which evaluates water quality and point source loadings', Assesss, which evaluates selected water quality stations and/or discharges', Data Mining, which links data elements using tables and maps, and Watershed Reporting, which provides automated report generation. The pre- and post-processing procedures that simplify running HSPF. Finally, the BASINS model is actively been developed. There are plans to incorporate SWAT as a module in BASINS, and discussions have been held to include PRZM 3 or some of its modules within BASINS.

There are disadvantages to simulating the impact of field applications of pesticides on stream water quality using the NPSM module in BASINS. First, the calibration of HSPF requires extensive time and experience. Also, crop growth factors and agricultural management procedures are not include in NPSM or HSPF. Moreover, if the PRZM 3 module is added, these factors and procedures will most likely be added at that time.

References

Beyerlein, D.C. and J.T. Brasher. 1994. May Creek Calibration Report. Prepared for King County Surface Water Management and the City of Renton Surface Water Utility, Seattle, WA. Prepared by AQUA TERRA Consultants, Everett, WA.

Chen, Y.D., S.C. McCutcheon, R.F. Carsel, A.S. Donigian, Jr., J.R. Cannell, and J.P. Craig. 1995. Validation of HSPF for the Water Balance Simulation of the Upper Grande Ronde Watershed, Oregon, USA. In: Man's Influence on Freshwater Ecosystems and Water Use. G. Petts (ed). International Association of Hydrological Sciences, IAHS Pub. No. 230. pp 3-13.

Chen, Y.D., R.F. Carsel, and S.C. McCutcheon. 1996. Stream Temperature Simulation of Forest Watersheds: Part 1. Enhancement of HSPF Modeling System, and Part 2. Application Study in the Upper Grande Ronde River, Oregon. Water Resources Bulletin (submitted for publication).

Donigian, A.S., Jr., and N.H. Crawford. 1976. Modeling Pesticides and Nutrients on Agricultural Lands. Environmental Research Laboratory, Athens, GA. EPA 600/2-7-76-043. 317 p.

Donigian, A.S., Jr., J.C. Imhoff and B.R. Bicknell. 1983. Modeling Water Quality and the Effects of Best Management Practices in Four Mile Creek, Iowa. EPA Contract No. 68-03-2895, Environmental Research Laboratory, U.S. EPA, Athens, GA. 30613.

Hess, G.W. 1996. Progress Report on Daily Flow-Routing Simulation for the Carson River, California and Nevada. U.S. Geological Survey Open File Report 96-211. U.S.G.S., Carson City, NV.

USDA Soil Water Assessment Tool (SWAT),

I. Introduction

SWAT (Soil and Water Assessment Tool) is the continuation of a long-term effort of nonpoint source pollution modeling with the USDA-Agricultural Research Service (ARS). In the early to mid-1970's, a model called CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems) was developed. CREAMS is a field scale model developed to simulate the impact of land management on water, sediment, nutrients, and pesticides leaving the edge of a field. By the early and mid-1980's, several models were being developed with origins from the original CREAMS model. GLEAMS (Groundwater Loading Effects on Agricultural Management Systems) concentrated on pesticide and nutrient groundwater loadings. A model called EPIC (Erosion-Productivity Impact Calculator) was originally developed to simulate the impact of erosion on crop productivity and has now evolved into a comprehensive agricultural management, field scale, nonpoint source loading model. A model called SWRRB (Simulator for Water Resources in Rural Basins) was developed to simulate nonpoint source loadings from watersheds. SWRRB is a continuous time (daily time step model) that allows a basin to be subdivided into a maximum of ten subbasins.

Since the late 1980's, most of the SWRRB model development had been focused on problems involving water quality. Example additions include the GLEAMS pesticide fate component, optional SCS technology for estimating peak runoff rates, and newly developed sediment yield equations. Also in the late 1980's, SWRRB was utilized for smaller watersheds within the basin (up to a few hundred square kilometers), but it was necessary to simulate streamflow from much larger basins (several thousand square kilometers). This required the basin to be divided into several hundred subwatersheds. SWRRB was limited to ten subbasins and also had a simplistic routing structure with outputs routed from the subbasin outlets directly to the basin outlet. This problem led to the development of a model called ROTO (Routing Outputs to Outlet). ROTO was developed to take output from multiple SWRRB runs and route the flows through channels and reservoirs. ROTO provided a reach routing approach and overcame the SWRRB subbasin limitation by "linking" multiple SWRRB runs together. Thus, the SWAT model was developed by merging SWRRB and ROTO into one basin scale model.

II. Model Operation

SWAT is a continuous time model that operates on a daily time step. SWAT uses a command structure for routing runoff and chemicals through a watershed similar to the structure of HYMO. Commands are included for routing flows through streams and reservoirs, adding flows, and inputting measured data or point sources. Using a routing command language, the model can simulate a basin subdivided into grid cells or subwatersheds. Additional commands have been developed to allow measured and point source data to be input to the model and routed with simulated flows.

Using the transfer command, water can be transferred from any reach or reservoir to any other reach or reservoir within the basin. The user can specify the fraction of flow to divert, the minimum flow remaining in the channel or reservoir, or a daily amount to divert. The user can also apply water directly to a subbasin for irrigation. Although the model operates on a daily time step and is efficient enough to run for many years, it is intended as a long term yield model and is not capable of detailed, single-event, flood routing.

III. Model Components

SWAT has two major classes of components: subbasin components and routing components.

Subbasin Components

The subbasin components of SWAT can be placed into eight major divisions--hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, and agricultural management.

Hydrology - The considerations include surface runoff, percolation, lateral subsurface flow, groundwater flow, evapotranspiration, snow melt, transmission losses, and ponds.

Weather - The weather variables necessary for driving SWAT are precipitation, air temperature, solar radiation, wind speed, and relative humidity. If daily precipitation and maximum/minimum temperature data are available, they can be input directly to SWAT. If not, the weather generator can simulate daily rainfall and temperature. Solar radiation, wind speed, and relative humidity are always simulated. One set of weather variables may be simulated for the entire basin, or different weather may be simulated for each subbasin.

Sedimentation - Sediment yield is estimated for each subbasin with the Modified Universal Soil Loss Equation. The hydrology model supplies estimates of runoff volume and peak runoff rate. The crop management factor is evaluated as a function of above-ground biomass, crop residue on the surface, and the minimum C factor for the crop. Other factors of the erosion equation are evaluated as described by Wischmeier and Smith.

Soil Temperature - Daily average soil temperature is simulated at the center of each soil layer for use in hydrology and residue decay. The temperature of the soil surface is estimated using daily maximum and minimum air temperature and snow, plant, and residue cover for the day of interest plus the four days immediately preceding. Soil temperature is simulated for each layer using a function of damping depth, surface temperature, and mean annual air temperature. Damping depth is dependent upon bulk density and soil water.

Crop Growth Model - A single model is used in SWAT for simulating all crops. Energy interception is estimated as a function of solar radiation and the crop's leaf area index. The potential increase in biomass for a day is estimated as the product of intercepted energy

and a crop parameter for converting energy to biomass. The leaf area index is simulated with equations dependent upon heat units. Crop yield is estimated using the harvest index concept. Harvest index increases as a non-linear function of heat units from zero at planting to the optimal value at maturity. The harvest index may be reduced by water stress during critical crop stages (usually between 30 and 90% of maturity).

Nutrients - Subbasin nutrient yield and nutrient cycling were taken from the EPIC model and modified as necessary for inclusion into the SWAT model. SWAT allows for simultaneous computations on each subbasin and routes the water, sediment, and nutrients from the subbasin outlets to the basin outlet. Nitrogen and Phosphorus are considered separately in SWAT.

Pesticides - GLEAMS technology for simulating pesticide transport by runoff, percolate, soil evaporation, and sediment was added to SWAT. Pesticides may be applied at any time and rate to plant foliage or below the soil surface at any depth. The plant leaf-area-index determines what fraction of foliar applied pesticide reaches the soil surface. Also, a fraction of the application rate (called application efficiency) is lost to the atmosphere. Each pesticide has a unique set of parameters including solubility, half life in soil and on foliage, wash off fraction, organic carbon adsorption coefficient, and cost. Pesticide on plant foliage and in the soil degrade exponentially according to the appropriate half lives. Pesticide transported by water and sediment is calculated for each runoff event and pesticide leaching is estimated for each soil layer when percolation occurs.

Agricultural Management - SWAT allows for unlimited years of crop rotations and up to three crops per year. The user can also input irrigation, nutrient, and pesticide application dates and amounts.

Routing Components - The routing components of SWAT include channel routing and reservoir routing. The channel routing consists of channel flood routing, impoundment routing, channel sediment routing, and channel nutrient and pesticide routing. The reservoir routing consists of reservoir water balance and routing, reservoir sediment routing, and routing of nutrients and pesticides.

IV. GIS Interface

An interface was developed for SWAT using the Graphical Resources Analysis Support System (GRASS). GRASS is a public domain raster GIS, designed and developed by the Environmental Division of the U.S. Army Construction Engineering Research Laboratory (USA-CERL), in Champaign, Illinois. GRASS is a general purpose, raster graphic modeling and analysis package initially developed for land and environmental planners at military installations. One of the major advantages of using GRASS is its “openness” with source code availability, which makes interfacing models easier.

The SWAT/GRASS input interface consists of three major divisions (1) project manager; (2) extract and aggregate inputs for the model; and (3) view, edit and check the input for model. The function of the project manager is to interact with the user to collect, prepare, edit and store basin and subbasin information to be formatted into a SWAT input file. Most of the SWAT input data are derived from GRASS raster/site layers. The data collected by the interface include: (1) basin attributes such as area of the basin, its geographic locations, (2) soil attributes needed for the SWAT model are extracted from STATSGO database, (3) topographic attributes include, accumulated drainage area, overland slope, overland slope length, channel dimensions, channel slope and channel length, and (4) land use attributes including crop name, planting and harvesting dates based on the heat unit scheduling and weather generator station information.

The output interface allows the user to display output maps and graph output data by selecting a subbasin from a GIS map. A similar interface compatible with ArcView/ArcInfo has also been developed.

V. Model Inputs and Outputs

Inputs

SWAT files are split into separate files by subbasin and data type. This facilitates more subbasins and simplifies GIS linkages. SWAT reads a file name, opens that file, reads and stores the input data, and then closes the file. This eliminates the problem of having more files open then the operating system allows.

For each subbasin, there are nine files required that contain inputs specific to each subbasin. They are (1) general input file, (2) routing input file, (3) pond input file, (4) chemical input file, (5) soils input files, (6) management input file, (7) management code input file, (8) groundwater input file, and (9) weather generator input file.

The following three routing files are used to input data to the model from other sources. These sources include measured and point sources and output from other model (EPIC). Values input from these files can be routed along with subbasin output simulated within SWAT. The first file contains daily output from the EPIC model. Output includes water, sediment, nutrient, and pesticide yields. EPIC will automatically write this file if specified by the EPIC user. The second file contains daily values of water, sediment, nutrient, and pesticide yields. It has a slightly different format from the EPIC file and is included to allow measured or point sources. The third file contained measured monthly streamflow. The file is closed and monthly values are stored in the model. This allows an unlimited number of monthly streamflow files to be used in a SWAT run.

Outputs

The main output files include general standard outputs, subbasin outputs, reach outputs, big subbasin outputs, and reservoir outputs. Except the first output file, all other files are written in "spreadsheet" format and can be output on daily, monthly, or annual basis.

SWAT uses a concept called "hydrologic response units" (HRU's) within a topographically-defined subbasin. Once the subbasins are defined, multiple HRU's within the subbasin can be defined. Model inputs including weather, soils, groundwater, and management, etc., are simulated for each HRU. Soil water balance, crop growth, nutrient cycling, management, etc., are simulated for each HRU. Components of the water balance for all HRU including water yield are all weighted for the subbasin.

VI. Model Applications

The SWAT model has been extensively used for national applications (see the HUMUS project: http://srph.tamu.edu/humus/) as well as in more regional projects such as NOAA's Coastal AssessmentFramework (see http://www-orca.nos.noaa.gov/projects/gomaine) and several larger scale projects (see http://srph.tamu.edu/swat) to determine subbasin water balances, stream flows, and non-point source pollution. The SWAT model uses GLEAMS technology in many of the overland pesticide components, and includes pesticide routing in-streams, and pesticide movement in lakes. The SWAT pesticide routines have been in use by USDA-ARS, universities, and industrial users(example, Bayer Corporation).

The SWAT model has been applied in several major projects: (1) Hydrological Unit Modeling of United States (HUMUS), (2) Coastal Watershed Assessment of Gulf of Maine, (3) Linking GIS and QUAL2L with SWAT, and (4) Hydrological Modeling of Rio Grande/Rio Bravo International Watershed.

The HUMUS system was built to address the national/regional scale water quality and quantity concerns. It was designed to provide the technical basis for conducting the appraisal of water resources for the 1997 RCA Appraisal Report. Approximately 2,150 watershed areas (the 8-digit USGS hydrologic unit areas) will be simulated using the HUMUS frame work and will be validated against the stream flows over 350 locations (the 6-digit USGS hydrologic unit areas).

The SWAT model was used to develop an inventory of land-based point and nonpoint pollution sources for the Gulf of Maine regional watershed and to establish a strategy to reduce pollution of the Gulf of Maine from significant sources.

The SWAT model was linked with the instream kinetics of the instream water quality model (QUAL2E) and applied to simulate the hydrology and water quality in the Wister Lake watershed located in the Arkansas river basin.

The SWAT model was used to simulate the transport of sediment and toxic materials in the International Rio Grande/Rio Bravo watershed for the better understanding of the dynamics of ecosystem impacts.

VII. Model Validation

The model validation effort is on-going. The following table summaries the validation works involved with various watersheds. The list of references of these validation works is also included.

Location	Reference	Drainage Area (km^2)	Water Yield/ Stream Flow	Soil Water	Surface Runoff	Base Flow	Soil ET	GW ET	GW Recharge	Plant Biomass
1. Middle Bosque River, TX	Arnold et al. (1993)	471	X		X	X			X	
2. Coshocton, OH	Arnold and Williams (1985)	lysimeter					X			
3. Bushland, TX	Arnold and Williams (1985)	field plot					X			X
4.Riesel, TX, Sonora, TX	Savabi *et al.* (1988) Savabi *et al.* (1988)	1.3 4.1	X X	X X			X			
5. Seco Creel, TX	Srinivasan and Arnold ((1988)	114	X							
6. Neches River Basin, TX	King *et al.* (1998)	25,032	X							
7. Colorado River Basin, TX	King *et al.* (1995)	40,407	X							
8. Lower Colorado, TX	Rosenthal *et al.* (1995)	8,927	X							
9. White Rock Lake, TX	Arnold *et al.* (1988)	257	X							
10. North Carolina	Jacobsen *et al.* (1995)	4.6	X		X					
11. Goose Creek, IL	Anrold and Allen (1996)	246	X	X	X	X	X	X	X	
12. Hadley Creek, IL	Arnold and Allen (1996)	122	X	X	X	X	X	X	X	
13. Panther Creek, IL	Arnold and Allen (1996)	188	X	X	X	X	X	X	X	
14. Goodwin Creek Watershed, MS	Bingner *et al.* (1996)	21.3	X							
15. Watersheds in OK, OH, GA, ID, MS, VT, AZ	Arnold *et al.*.(1987)	9.0-538	X							
16. Bushland, TX	Arnold and Stockle (1990)	field plot								X

References of Validation Works

Arnold, J. G. and P. M. Allen. 1996. Estimating hydrologic budgets for three Illinois watersheds. Journal of Hydrology, 176(1996):55-77.

Arnold, J. G., P. M. Allen, and G. Bernhardt. 1993. A comprehensive surface-groundwater flow model. Journal of Hydrology. 142: 47-69.

Arnold, J. G. and Stockle, C.O. 1990. Simulation of supplemental irrigation from on-farm ponds. Journal of Irrigation and Drainage Division. ASCE 117(3): 408-424.

Arnold, J. G. and Williams, J. R. 1985. Evapotranspiration in a basin scale hydrologic model. In: Advances in Evapotranspiration. Proc. ASAE Symp., pp. 405-413.

Arnold, J. G. and Williams, J. R. 1987. Validation of SWRRB--Simulator for water resources in rural basins. ASCE Journal of Water Resour. Plann. and Manage. 113:(2):243-256.

Binger, R. L., C. V. Alonso, J. G. Arnold, and J. Garbrecht. 1996. Validation of the GRASS-TOPAZ-SWAT sediment yield scheme using measurements from the Goodwin Creek watershed. Federal Interagency Sedimentation Conference. Las Vegas, March, 1996.

Jacobson, B.M., J. Feng, G. D. Jennings, and K. C. Stone. 1995. Watershed scale non-point source model evaluation for the North Carolina coastal plain. Proc. Intl. Symp. on Water Quality Modeling. ASAE Publ No. 05-95. Orlando, Florida. 186-191.

King, K. W., Arnold, J. G., Srinivasan, R., and Williams, J. R. 1998. Sensitivity of river basin hydrology to CO2 and temperature. ASCE J. of Water Resources Planning and Management (in review).

Rosenthal, W. D., Srinivasan, R., and Arnold, J. G. 1995. Alternate river management using a linked GIS-hydrology model. Trans. ASAE 38 (3): 783-790.

Savabi, M. G., Arnold, J. G., and Richardson, C.W. 1989. Modeling the effect of brush control on rangeland water yield. Water Resources Bull. 25 (4): 855-865.

Sophocleous, M.A., Koelliker, J.K., Govindaraju, R.S., Birdie, T., Ramireddygari, S.R., and Perkins, S.P. 1998. Integrated Numerical modeling for basin-wide water management: The case of the Rattlesnake Creek Basin in South-central Kansas. J. of Hydrology (in review).

Srinivasan, R., Arnold, J., Muttiah, R.S., Walker, C. and Dyke, P.T. 1993. Hydrologic unit model of the United States (HUMUS). In: Proc. Adv. In Hydro-Science and Eng. Univ. of Mississippi. Oxford, MS.

Srinivasan, R., and J. G. Arnold. 1994. Integration of a Basin-Scale Water Quality Model with GIS. Water Resources Bulletin (30) 3: 453-462.

VIII. Model Availability and Support

The SWAT model is written in FORTRAN 90 and has been implemented in PC system (Windows 95 and Windows-NT) and workstations (IBM, Sun and HP). The model is in the public domain. The source code, execution code and use manual with some testing examples are available through the SWAT homepage on internet. The address is

http://www.brc.tamus.edu/swat.

There is also an on-line user group support. The contacts of the technical support are listed below:

Name	E-mail Address	Phone Number
Jeff Arnold	arnold@brcsun0.tamu.edu	(254)770-6502
Nancy Sammons	sammons@brcsun0.tamu.edu	(254)770-6512
R. Srinivasan	srin@brcsun0.tamu.edu	(254)770-6670

IX. Critical Assessment

Strength of the Model - The SWAT model is well tested and validated. It reflects the advancement of the nonpoint source pollution modeling technology as evolved through CREAMS, GLEAMS, SWRRB, EPIC and ROTO. It is a public domain and has a strong technical support as well as an on-line user group support. The SWAT is a complete package and is capable to simulate very large scale watersheds without the linkage to other field scale models.

Weakness of the Model - Extensive learning is required to use the SWAT model, which is a prerequisite for almost every watershed scale model. In addition to the knowledge in hydrology, the users also need GIS training to use this model. Due to its large data input requirement and detailed output results, the limiting factor for implementing this model is the availability of resources both in time and people.

References

Information on SWAT was obtained from the SWAT webpage at www.bre.tamus.edu/swat. Model validation information was provides by Dr. Jeff Arnold at USDA-ARS.

USDA Annual Agricultural Non-Point Source (AnnAGNPS)

The AnnAGNPS information was summarized based on the draft publication prepared by Bosch, D., F. Theurer, R. Bingner, G. Felton and I. Chaubey. 1998. *Draft* Evaluation of the AnnAGNPS Water Quality Model. ASAE National Meeting, Orlando Florida, 12-15 July 1998, ASAE Paper No. 98-2195.

Introduction

AnnAGNPS is a continuous-simulation, multi-event modification of AGNPS with improved technology and the addition of new features. The model can be used to predict non-point source pollutant loadings from agricultural watersheds. It is a tool for comparing the effects of implementing various conservation alternatives within the watershed. Cropping systems, fertilizer application rates, water and dissolved nutrients from point sources, sediment with attached chemicals from gullies, soluble nutrient contributions from feedlots, and the effect of terraced fields can be modeled. Version 1 of the AnnAGNPS was released in February 1998. It included all the features that were in the original AGNPS plus pesticides, source accounting, settling of sediments due to instream impoundments, and the Revised Universal Soil Loss Equation. A new release is imminent (planned for this summer) that will include snowmelt and frozen soil components.

The Agricultural Non-Point Source (AGNPS) model was developed in the early 1980's by the Agricultural Research Service (ARS) in cooperation with the Minnesota Pollution Control Agency, and the Natural Resource Conservation Service (NRCS) (Young et al., 1989; Young et al., 1995). The model was developed to analyze and provide estimates of runoff water quality from agricultural watersheds ranging in size from a few hectares to 20,000 ha. Because of it's ease of use, flexibility, and relative accuracy, AGNPS is widely applied throughout the world to investigate various water quality problems.

II. Model Operation

AGNPS is a single-event model. Early in it's development, this was recognized as a serious model limitation. In the early 1990's, a cooperative team of ARS and NRCS scientists was formed to develop an annualized continuous-simulation version of the model, AnnAGNPS. Coordination of the effort was originally supervised by the ARS, North Central Soil Conservation Laboratory in Morris, Minnesota, later was transferred to the NRCS, National Water and Climate Center, Water Science and Technology Team in Beltsville, Maryland for the initial release, and subsequently the research and development lead was given to the ARS, National Sedimentation Laboratory in Oxford, Mississippi. NRCS in Beltsville will continue to provide the technology transfer support for AnnAGNPS. AnnAGNPS is the pollutant loading model for a suite of water quality models called AGNPS 98.

AnnAGNPS is a continuous-simulation, watershed-scale model intended to be used as a tool to evaluate non-point source pollution from agricultural watersheds ranging in size up to 300,000 ha.

It is an expansion of the capabilities of AGNPS and as such shares many similarities to the original model. The watershed is subdivided into homogenous land areas with respect to soil type, land use, and land management. These areas can be of any shape from the original square grid cells of AGNPS to the more appropriate hydrologic boundaries that can be generated by terrain-following GIS software. AnnAGNPS simulates quantities of surface water, sediment, nutrients, and pesticides leaving the land areas (cells) and their transport through the watershed. The model can be used to examine current conditions or to compare the effects of implementing various conservation alternatives over time within the watershed. Alternative cropping and tillage systems, fertilizer, pesticide, and irrigation application rates, point source loads, and feedlot management can be evaluated.

III. Model Components

AnnAGNPS calculations are performed on a daily time step. AnnAGNPS simulates water, sediment, nutrients, and pesticide transport over the landscape and through the stream system. Special components are included to handle concentrated sources of nutrients from feedlots and point sources, concentrated sediment sources with attached chemicals from gullies, and irrigation (water with dissolved chemicals and sediment with attached chemicals). Each day the applied water and resulting runoff is routed through the watershed system before the next day is considered. No water except for that contained within the soil column is carried over from one day to the next.

The model partitions soluble nutrients and pesticides between surface runoff and infiltration. Sediment-transported nutrients and pesticides are also calculated and equilbrated within the stream system. Sediment is subdivided into 5 particle size classes (clay, silt, sand, small aggregate, and large aggregate). Particle sizes are routed separately in the stream reaches.

Surface Runoff and Soil Moisture - For purposes of runoff generation and soil water storage, the soil profile is divided into two layers. The top 200 mm are used as a tillage layer whose properties can change (bulk density, etc.) and the remaining soil profile comprises the second layer whose properties remain static. A daily soil moisture water budget considers applied water (rainfall, irrigation, and snowmelt), runoff, evapotranspiration, and percolation. Runoff is calculated using the SCS Runoff Curve Number equation (Mockus, 1972), but is modified if a shallow, surface frozen soil layer exists. Curve numbers are modified daily based upon tillage operations, soil moisture, and crop stage. Actual evapotranspiration is a function of potential evapotranspiration calculated using the Penman equation (Penman, 1948) and soil moisture content.

Time of concentration in each cell can either be input or calculated by the model. If calculated, cell time of concentration is the sum of the travel times from the hydraulically most distant point for overland flow, shallow concentrated flow, and concentrated flow within the cell. Calculations for the three flow types are based upon the NRCS TR-55 (SCS, 1986) procedures, modified by Theurer and Cronshey (1998). The first 50 m of flow length are treated as overland flow. The next 50 m are treated as shallow concentrated flow, while the length beyond this is treated as concentrated flow.

Erosion - Overland erosion of sediment is determined using RUSLE (Renard et al., 1997) and was modified to work at the watershed-scale in AnnAGNPS (Geter and Theurer, 1998).

Nutrients - A daily mass balance for nitrogen (N), phosphorous (P), and organic carbon (OC) is calculated for each cell. Major components considered are plant uptake of N and P, fertilization, residue decomposition, and N and P transport. Soluble and sediment adsorbed N and P are calculated. N and P are further partitioned into organic and mineral phases. Plant uptake of N and P are modeled through a simple crop growth stage index.

Pesticides - A daily mass balance adapted from the GLEAMS (Leonard et al., 1987) model is computed for each pesticide. AnnAGNPS allows for any number of pesticides, each with their own independent chemical properties. Each pesticide is treated separately, independent equilibration is assumed for each pesticide. Major components of the pesticide model include foliage washoff, vertical transport in the soil profile, and degradation. Soluble and sediment adsorbed fractions are calculated for each cell on a daily basis.

Reach Routing - The methods used to route sediment, nutrients, and pesticides through the watershed are outlined in Theurer and Cronshey (1998) and briefly discussed here. Peak flow for each reach is calculated using an extension of the TR-55 graphical peak discharge method (Theurer and Cronshey, 1998). Sediment routing is calculated based upon transport capacity relationships using the Bagnold stream power equation (Bagnold, 1966). Sediments are routed by particle size class where each particular size class is deposited, more entrained, or transported unchanged depending upon the amount entering the reach, availability of that size class in the channel and banks, and the transport capacity of each size class. If the sum of all incoming sediment is greater than the sediment transport capacity, then the sediment is deposited. If that sum is less than or equal to the sediment transport capacity, the sediment discharge at the downstream end of the reach will include bed & bank material if the user has indicated that it is an erodible reach.

Nutrients (N, P, and OC) and pesticides are subdivided into soluble and sediment attached components for routing. Attached P is further subdivided into organic and inorganic. Each nutrient component is decayed based upon the reach travel time, water temperature, and an appropriate decay constant. Soluble nutrients are further reduced by infiltration. Attached nutrients are adjusted for deposition of clay particles. Equilibrium concentrations are calculated at both the upstream and downstream points of the reach. A first-order equilibration model is used.

IV. Interfaces

Current interfaces for the model include:

- A Windows-based flow network generator (using Digital Elevation Model data) which can be used to subdivide the watershed into hydrologically-derived cells (the grid map) and to provide basic land information such as areas, slopes, and elevation.

- A Windows-based input editor for inputing or modifying AnnAGNPS input data.

- A Windows-based post processor for examining model output.

- Input data converter for old AGNPS data to AnnAGNPS input. AnnAGNPS can be run on an event basis after converting the AGNPS input file.

- A set of reference databases to assist with developing the input parameters.

V. Model Inputs and Outputs

AnnAGNPS includes 34 different categories of input data (Cronshey and Theurer, 1998). These can be further grouped into the following major classifications: climate, land characterization, field operations, chemical characteristics, and feedlot operations. The climatic data consist of precipitation, maximum and minimum air temperature, relative humidity, sky cover, and wind speed. Land characterization data include soil characterization, curve number, RUSLE parameters, and watershed drainage characterization. Field operation data include tillage, planting, harvest, rotation, chemical operations, and irrigations schedules. Feedlot operations include daily manure production rates, times of manure removal, and residual amount from previous operations.

Input is facilitated by an input editor which is currently available with the model. Input and output can be in either all English or all metric units. Separate input files for watershed data (AnnAGNPS input) and simulation period climate data (daily climate data) allows for quick changing of climate data. Extensive data checks (with appropriate error messages) are performed as data is read and, to a lesser extent, after all data is read.

Output is expressed on an event basis for selected stream reaches and as source accounting from land or reach components over the simulation period. Output parameters are selected by the user for the desired watershed source locations (specific cells, reaches, feedlots, point sources, and gullies) for any simulation period. Source accounting indicates the fraction of a pollutant loading passing through any reach in the stream network that came from the user identified watershed source location. Multiple watershed source and reach locations can be identified. Additionally, event quantities for user-selected parameters can be output at desired stream reach locations.

VI. Model Applications and Validation

At this time the model is being used by a number of scientists and NRCS field personnel. There are no published validations of the model. While a sensitivity test has not been conducted, the technology was based upon the science found in AGNPS (Young et al., 1994) , GLEAMS (Knisel, 1993), EPIC (Williams et al., 1989), WEPP (Flanagan & Nearing, 1995), and RUSLE (Renard et al., 1997) models which have undergone sensitivity analyses (Young et al., 1987). Other references pertaining to testing and application of the AGNPS model are: Hession et al. (1988), Park and Kim (1995), Parson et al. (1996), Prasher et al. (1995), Sathyakumar and Farrell-Poe (1995), Young et al. (1989), and Young et al. (1995).

VII. Future Developments

Future developments to the AnnAGNPS model include adding snowmelt and frozen soil components which is planned for release in September 1998, ground water and lake modules, a weather generator to compute individual storm characters for a chosen location, and a complete GIS input/output display interface.

VIII. Model Availability and Support

Model Availability and Source Version 1 of AnnAGNPS is currently available via the AGNPS 98 web site at http://www.sedlab.olemiss.edu/AGNPS98.html. Additional features are being added and more are planned for the future. Snowmelt and frozen soil features will be added in the very near future. Groundwater is planned for a future release. Executable files are available for the AGNPS to AnnAGNPS converter, AnnAGNPS model, flownet generator, and input and output editors. Limited documentation is available for each of these components at this web site. Additional documentation can be found in Cronshey and Theurer (1998), Geter and Theurer (1998), Theurer and Cronshey (1998), and Bingner et al. (1998).

IX. Limitations and Applicability

The following limitations to the model are acknowledged by the developers:

- All runoff and associated sediment, nutrient, and pesticide loads for a single day are routed to the watershed outlet before the next day simulation begins (regardless of how many days this may actually take).
- There is no tracking of nutrients and pesticides attached to sediment deposited in stream reaches from one day to the next
- Point sources are limited to constant loading rates (water and nutrients) for entire simulation period.
- Preprocessing software (flow net generator and input editor) are written in Visual Basic

for a Windows environment so they will not operate on a DOS-only system.

References

Bagnold, R.A. 1966. An approach to the sediment transport problem from general physics. Prof. Paper 422-J. U.S. Geol. Surv., Reston, Va.

Bingner, R.L., R.W. Darden, F.D. Theurer, C.V. Alonso, and P. Smith. 1998. AnnAGNPS input parameter editor interface. Proceedings of the First Federal Interagency Hydrologic Modeling Conference. Proceedings of the First Federal Interagency Hydrologic Modeling Conference. Las Vegas, Nevada. April 19-23, 1998. p. 8-15 to 8-18.

Cronshey, R.G. and F.D. Theurer. 1998. AnnAGNPS - Non-point pollutant loading model. Proceedings of the First Federal Interagency Hydrologic Modeling Conference. Proceedings of the First Federal Interagency Hydrologic Modeling Conference. Las Vegas, Nevada. April 19-23, 1998. p. 1-9 to 1-16.

Flanagan, D.C. and M.A. Nearing (ed.) 1995. USDA—Water Erosion Prediction Project (WEPP). NSERL Report No. 10, National Soil Erosion research Laboratory, USDA-ARA-MWA. July 1995.

Geter, W.F. and F.D. Theurer. 1998. AnnAGNPS - RUSLE sheet and rill erosion. Proceedings of the First Federal Interagency Hydrologic Modeling Conference. Proceedings of the First Federal Interagency Hydrologic Modeling Conference. Las Vegas, Nevada. April 19-23, 1998. p. 1-17 to 1-24.

Hession, W.C., R.A. Young, and C.A. Onstad. 1988. Simulation of site-specific sediment deposition with the AGNPS model. ASAE winter meeting. Paper no. 88-2534.

Knisel, W.G. (ed.) 1993. . GLEAMS: Groundwater loading effects of agricultural management systems. USDA-ARS-SEWRL, UDA-CPES-BAED, Pub. No. 5.

Leonard, R.A., W.G. Knisel and D.A. Still. 1987. GLEAMS: Groundwater loading effects of agricultural management systems. Transactions of the ASAE. 30(5):1403-1418.

Mockus, V. 1972. Estimation of direct runoff from storm rainfall. In National Engineering Handbook. NEH Notice 4-102, August 1972. p. 10.1-10.22.

Park, S.W. and J. T. Kim. 1995. Validating AGNPS model with complex topography in central Korea. ASAE annual meeting. Paper no. 952702. 18 pp.

Parson, S.C., Hamlett J.M., Robillard, P.D. and Foster, M. 1996. The impact of uncertainty on decision making with AGNPS. ASAE paper no. 96-2063. 22 pp.

Penman, H.L. 1948. Natural evaporation from open water, bare soil, and grass. Proc. Roy. Soc. (London), Ser. A. 193: 120-145.

Prasher, S.O., R.B. Bonnell, and J.A. Millette. 1995. An integrated approach for pesticide pollution on a watershed scale. ASAE annual meeting. Paper no. 952575. 13 pp.

Renard, K. G., Foster, G. R., Weesies, G. A.,. McCool, D. K., and Yoder, D. C., coordinators. 1997 Predicting Soil Erosion by Water: A Guide to Conservation Planning With the Revised Universal Loss Equation (RUSLE). USDA Agriculture Handbook No. 703, 404 p

Sathyakumar, R. and K.L. Farrell-Poe. 1995. Predicting rural municipal nonpoint source pollution using GIS and AGNPS. ASAE annual meeting. Paper no. 953241. 19 pp.

Soil Conservation Service. 1986. Urban hydrology for small watersheds. USDA Soil Conservation Service. Technical Release 55.

Theurer, F.D. and R.G. Cronshey. 1998. AnnAGNPS - Reach routing processes. Proceedings of the First Federal Interagency Hydrologic Modeling Conference. Proceedings of the First Federal Interagency Hydrologic Modeling Conference. Las Vegas, Nevada. April 19-23, 1998. p. 1-25 to 1-32.

U.S. Geological Survey. Proceedings of the U.S. Geological Survey Sediment Workshop, February 4-7, 1997.

Williams, J.R., P.T. Dyke, W.W. Fuchs, V.W. Benson, O.W. Rice, and E.D. Taylor. 1989. EPIC—Erosion/Productivity Impact Calculator: 2. User Manual. A.N. Sharpley and J.R. Williams, editors. U.S. Department of Agriculture Technical Bulletin No. 1768.

Young, R.A., C.A. Onstad, D.D. Bosch, and W.P. Anderson. 1995. AGNPS: An agricultural nonpoint source model. In Computer Models of Watershed Hydrology. Singh, V.P. (ed.). Water Resources Publications. Highlands Ranch, CO. pp. 1011-1020.

Young, R.A., C.A. Onstad, D.D. Bosch, and W.P. Anderson. 1989. AGNPS: A nonpoint-source pollution model for evaluating agricultural watersheds. J. of Soil and Water Conservation. 44(2):168-173.

Young, R.A., C.A. Onstad, D.D. Bosch, and W.P. Anderson. 1987. AGNPS, Agricultural nonpoint source pollution model: A large watershed analysis tool. USDA, ARS Conserv. Res. Report # 35. 77 pp.

Young, R.A., C.A. Onstad, D.D. Bosch, and W.P. Anderson. 1994. *AG*ricultural *N*on-*P*oint *S*ource Pollution Model, Version 4.03 *AGNPS* USER'S GUIDE. July 1994. USDA-NRS-NSL, Oxford, MS.