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EVALUATION OF THE AnnAGNPS WATER QUALITY MODEL

by

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Summary:
This paper describes the capabilities of the Annualized Agricultural Non-Point Source model, AnnAGNPS. 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. Version 1 of AnnAGNPS was released in February 1998.

Keywords: water quality modeling, watershed management, nonpoint source pollution

Evaluation of the AnnAGNPS Water Quality Model [1,2]

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Abstract

This paper describes the capabilities of the Annualized Agricultural Non-Point Source model, AnnAGNPS. The manuscript presents an evaluation of the model based upon a standard set of criteria developed by the "Agricultural Water Quality Committee", sponsored by American Society of Civil Engineers (ASCE), Water Resources Engineering Division and the Southern Regional Research Project (S-273). This evaluation discusses model capabilities, appropriate applications, sensitivity, testing, and availability. 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 AnnAGNPS was released in February 1998. It includes all the features that were in the original AGNPS plus pesticides, source accounting, settling of sediments due to in-stream impoundments, and the Revised Universal Soil Loss Equation. An upgrade that will include snow-melt and frozen soil components is expected in 1998.

Introduction

Project Background

Computer simulation models are widely used to assess environmental impacts of agricultural practices. Today, there exist numerous different models, frequently developed for very specific tasks. As a means to establish a comprehensive set of guidelines for application of these models, a joint task committee, "Agricultural Non-point Source Water Quality Models: Their Use and Application", was formed. The committee is sponsored by ASCE's Water Resources Engineering Division, Agricultural Water Quality Committee, and the USDA Cooperative State Research, Education, and Extension Service (CSREES) Southern Region Project S-273, "Development and Application of Comprehensive Agricultural Ecosystem Models". As part of this process, twenty different agricultural non-point source pollution models were identified for evaluation. The subject of this paper is the critical evaluation of one of these models, the Annualized Agricultural Non-Point Source Pollution Model (AnnAGNPS).

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[1] Contribution from the USDA-ARS, Southeast Watershed Research Laboratory, 2375 Rainwater Road, P.O. Box 946, Tifton, GA 31793, in cooperation with Univ. of Georgia Coastal Plain Exp. Stn.

Objectives

The objectives of this evaluation are to:

1. Summarize the basic characteristics of the AnnAGNPS model.
2. Present current status and availability of the model.
3. Present an evaluation of current strengths and weaknesses of the model.

Model Use Characteristics

Model History

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 its ease of use, flexibility, and relative accuracy, AGNPS is widely applied throughout the world to investigate various water quality problems.

AGNPS is a single-event model. Early in its 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, and later was transferred to the NRCS, National Water and Climate Center, Water Science and Technology Team in Beltsville, Maryland. Research and development leadership was assumed by the ARS, National Sedimentation Laboratory in Oxford, Mississippi. NRCS in Beltsville provides technology transfer support for AnnAGNPS. AnnAGNPS is the pollutant loading model for a suite of water quality models referred to as AGNPS 98.

Intended Uses

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. A tabular summary of model components is presented in Table 1. The watershed is subdivided into homogenous land areas (cells) 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 more appropriate hydrologic boundaries that can be generated by terrain-following Geographical Information System (GIS) software. AnnAGNPS simulates quantities of surface water, sediment, nutrients, and pesticides leaving the 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

Table 1. Summary of the components of the AnnAGNPS model.

Characteristics	Incorporated in Model	Comments
spatial scale	watershed	limited by data availability and computer memory, drainage areas up to 300,000 ha
discretization	cells	square grid or hydrologic boundaries
temporal scale	daily time step	unlimited number of years
Water		
surface runoff	yes	SCS curve number and extended TR55
irrigation	yes	water with dissolved chemicals and sediment with attached chemicals
ground water	future development	
Sediment		
sheet and rill erosion	yes	RUSLE technology
gully erosion	yes	function of surface runoff volume
stream-bed and bank erosion	yes	by transport capacity
transport	yes	Einstein deposition equation with Bagnold transport capacity
impoundments	yes	settling time and dilution due to permanent storage
particle size classes	yes	five
Nutrients		
nitrogen	yes	dissolved and attached
phosphorous	yes	dissolved and attached
organic carbon	yes	dissolved and attached
pesticides	yes	unlimited number, dissolved and attached
feedlots	yes	dissolved nutrients only
point sources	yes	water and dissolved nutrients
gullies	yes	sediment and attached chemicals
snow-melt	release expected in 1998	based upon thermodynamic balance of snow-pack with surrounding environment
frozen soils	release expected in 1998	thermodynamic balance and heat transfer within soil column, includes effect on USLE soil "K" factor
economics	ongoing development with the NRCS Social Science Institute	minimization of pollutant loadings

cropping and tillage systems; fertilizer, pesticide, and irrigation application rates; point source loads; and feedlot management can be evaluated.

Target Audience

The primary target audiences for the AnnAGNPS model are the state and field offices of the NRCS. Other agencies involved in natural resource management will also find the model useful. A moderate level of understanding of NRCS-supported technology is necessary to develop the necessary input for the model and to interpret model output (e.g., Soil Conservation Service, SCS, curve numbers and the Revised Universal Soil Loss Equation, RUSLE). Modeling the environmental impact of various resource protection programs remains high on the list of needs of the NRCS (USGS, 1997). Models that are simple, reliable, and do not require users to key-in large amounts of data are especially needed. Models remain the most practical means to examine the flow of water and water transported pollutants on a watershed scale in a manner allowing planners to determine the effects of treatments over long time periods (risk analysis), and to examine the treatments needed based on landscape and watershed location. Models allow users to identify high priority treatment areas, a valuable tool for optimizing limited resources.

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. Snow-melt and frozen soil features will be added in 1998. Ground water is planned for a future release. Executable files are available to convert AGNPS input files to AnnAGNPS input file format, for the AnnAGNPS model, to generate flownets, and to edit input and output. 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).

AnnAGNPS is written in standard American National Standards Institute (ANSI) Fortran 90. AnnAGNPS version 1.0 is available as a 32-bit version for Windows 95. AnnAGNPS could also be used on other platforms that have a compiler for ANSI Fortran 90. The AnnAGNPS executable program is less than 1 MB in size. Additional memory is needed for dynamic data storage requirements during execution. The total memory requirement depends upon the number of cells and complexity of features used and could be as little as a few kilobytes for a small number of simple cells to much more for larger watersheds with more complex features. Additional hard disk storage is needed for user selected output and error files. Total memory requirements are dependent upon the watershed size and heterogeneity which dictate the number of cells and the complexity of features needed to represent the pollutant loading processes. However, normal Windows 95 operating system requirements (16 Mb memory and several Mb of available disk space) is sufficient for all but the largest, most complex jobs.

Verified Applications and Tests

At this time the model is being used by a number of scientists and NRCS field personnel. There are no published validations of AnnAGNPS. While a sensitivity test has not been conducted, AnnAGNPS technology was based upon science found in AGNPS (Young et al., 1994), GLEAMS (Knisel, 1993), EPIC (Williams et al., 1989), WEPP (Flanagan and 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).

Model Characteristics

Methods

AnnAGNPS calculations are performed on a daily time step. AnnAGNPS simulates water, sediment, nutrients, and pesticide transport at the cell and watershed levels. 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 are 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 equilibrated 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. Some of the specific methods used in various components of the model are also outlined in Table 1. Additional detail can be found in Cronshey and Theurer (1998), Geter and Theurer (1998), and Theurer and Cronshey (1998).

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.). The remaining soil profile comprises the second layer whose properties remain static. A daily soil moisture water budget considers applied water (rainfall, irrigation, and snow-melt), 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.

Most validation work on AGNPS has been on relatively small and responsive watersheds. Conditions with longer lag times associated with significant ground water fate and transport of nitrogen and many pesticides are largely untested. These conditions are significant on a watershed scale such as the Chesapeake Bay (166,000 km^2) but may be insignificant on watersheds in the 1 - 800 ha range.

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.

Relatively new information (Sharpley, 1995; Sharpley et al., 1994; Sharpley et. al., 1992; Edwards and Daniel, 1994; Edwards and Daniel, 1993; Coale and Olear, 1996) on fate and transport of phosphorus from areas with high soil test P have not yet been incorporated. Hence, predictions of P loss from fields with high animal manure applications may be conservative.

Pesticides

A daily mass balance adapted from GLEAMS (Leonard et al., 1987) 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 wash-off, 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 the sediment transport capacity, the sediment discharge at the downstream end of the reach will include bed and bank material if the user has indicated that it is an erodible reach.

Nutrients 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.

Calibration

As with all physical-process models, the model input can be refined by comparing model simulations to observed data. The selection of the curve number largely controls runoff volume in models which use SCS curve number technology. Because of the impact of runoff volume on all other hydrologic processes, it is expected that the curve number may be one of the most sensitive parameters in the AnnAGNPS model.

Input / Output

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 irrigation schedules. Feedlot operations include daily manure production rates, times of manure removal, and residual amount from previous operations.

There are over 400 separate input parameters necessary for model execution. Some of these parameters are repeated for each cell, soil type, land use, feedlot, and/or channel reach. Separate parameters are necessary for the model verification section. The daily climate data input set includes 22 parameters, 8 of which are repeated for each day simulated. Default values are available for some of the input parameters. Input of others can be simplified because of duplication over a given watershed. Some of the geographical inputs including cell boundaries, land slope, slope direction, and land use, can be generated by GIS and digital elevation models. Climatic parameters can be produced using weather generators in combination with local data.

Input is facilitated by an input editor which is currently available with the model. The input editor provides for data input in a page type format, with each of the 34 major data categories on a separate input page. Input and output can be in either all English or all metric units. Separate input files for watershed and climate data allows for quick changing of climatic input. Extensive data checks (with appropriate error messages) are performed as data are read and, to a lesser extent, after all data are read. Brief explanations of the input parameters are provided in the editor. Further explanations are provided in the "Input File Specification" documentation available at the AGNPS 98 web site (http://www.sedlab.olemiss.edu/AGNPS98.html).

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. Output analysis can be simplified by using the output editor also available at the AGNPS 98 web site. Documentation describing the output format is also available at this site.

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 and to provide basic land information such as areas, slopes, and elevation;
• A Windows-based input editor for inputting 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.

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 are no mass balance calculations tracking inflow and outflow of water;
• 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;
• There is no allowance for spatially variable rainfall.

Future Developments

Future developments to the AnnAGNPS model include:

• snow-melt and frozen soil components, planned for release in September 1998;
• ground water and lake modules;
• wetland and lake water quality components;
• weather generator to compute individual storm characters for a chosen location;
• integration of Next Generation Weather Radar (NEXRAD) technology;
• GIS input/output display interface;
• integration with the USDA-NRCS Hydrologic Unit Water Quality (HU/WQ) Tools modeling environment.

Summary

There is a great need for a flexible, accurate, discretized, continuous-simulation, watershed-scale, non-point source pollutant model. The success of such a model is largely determined by it's ease of use and the utility of the model output. The AnnAGNPS model appears to have been developed with these goals in mind. Considerable testing must be done before it can be judged as reliable and accurate. In addition, due to the extensive input requirements, additional tools need to be developed to ease the burden of developing input data sets for the model. However, as additional GIS tools are developed, this may not be an insurmountable task.

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