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# ANN-AGNPS: A CONTINUOUS SIMULATION WATERSHED MODEL

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## ABSTRACT

The Annualized Agricultural Nonpoint Source (ANN-AGNPS) model is a distributed parameter, continuous simulation model developed to simulate the behavior of watershed or catchments that have agriculture as their primary land use. It is based on the present AGNPS single event model and uses enhanced RUSLE routines. The basic components of the model include hydrology, sedimentation, and chemical transport. The model is cellular based with all characteristic inputs and calculations made at the cell level. Primary capabilities of the model include evaluation of the relative quantity and quality of outflow from a watershed in order to assess their pollution potential, identification of critical areas of nonpoint source pollutant production within a watershed, and evaluation of the effects on watershed outflow by applying alternative management practices on problem areas. A preliminary evaluation of the model on a monitored watershed is presented.

## INTRODUCTION

Reducing agricultural nonpoint source (NPS) pollution loading has received reinvigorated interest inside and outside of the agricultural community. The 1990 Farm Bill's Water Quality Protection Program (WQPP) was designed to address this concern by targeting farm assistance to areas where meaningful reduction in agriculture's contribution could be achieved. The conservation agent, responsible for carrying out the program, has three basic tasks: (1) identify those lands that contribute the majority of pollutants, (2) estimate the level of contribution generated by those identified lands, and (3) based upon the level of contribution, design cost efficient alternative farm management strategies that effectively reduce pollutant loading.

A large number of computer modeling tools have been developed and enlisted to aid in resource conservation planning and management for soil erosion and NPS pollutant mitigation. A list of several of the more widely used models for agricultural landscapes include: CREAMS (Knisel, 1980), EPIC (Williams, et al., 1984), SWRRB (Arnold, et al., 1990), GAMES (Rudra, et al., 1986), HSPF (Barnwell and Johanson, 1981), ANSWERS (Beasley, et al., 1980) and AGNPS (Young, et al., 1989).

Efficiently and effectively implementing the 1990 Farm Bill's WQPP will require the increased use of computer models. These models must not only achieve the above stated three required tasks, but they should also be capable of the following: (1) allow operation by local agents without extensive training, (2) utilize input parameters that are easily obtained from available local sources, (3) not need complicated parameterization, and (4) generate results the resource planner feels comfortable with in making equitable and impartial decisions.

The updated continuous simulation version of AGNPS, ANN-AGNPS (Annualized - Agricultural Nonpoint Source model) is a computer tool capable of performing those tasks required to successfully carry out the intent of the new water quality program. Integrating continuous simulation to the existing distributed spatial abilities of AGNPS enables an even more representative description of the stochastic physical processes controlling the movement of sediments and agricultural chemicals from the field into the surrounding environment. At the same time, ANN-AGNPS's user interface and integrated data bases make the model easier to use.

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## ANN-AGNPS STRUCTURE

The continuous version is based upon the AGNPS grid-cell representation of a watershed for delineating and identifying landscape and agronomic parameters as well as for entering the information into the data input spreadsheet. ANN-AGNPS routes water, associated sediments and nutrients through the watershed from cell to cell based upon directional flow information input by the user.

ANN-AGNPS, like AGNPS, generates results on watershed hydrology, including overland runoff volume, channel flow runoff volume, peak flow discharge rates, field erosion, channel sediment transport and deposition for five soil particle class sizes, and nutrient yields for Nitrogen (N) and Phosphorus (P) in both sediment-attached and water-soluble states, and for chemical oxygen demand (COD) in water-soluble form. Results can be viewed for any single cell within the watershed, a sub- basin within the watershed, or for the entire watershed in either tabular or graphical mapped format. Runoff events taking place within the simulation can be viewed individually, as a monthly or yearly accumulation of storm results, or as an average annual value derived from a multiple-year scenario.

## MODEL COMPONENTS

### AGNPS Routines in ANN-AGNPS

The ANN-AGNPS overland hydrology calculations continue to be based upon the use of the SCS curve number method. Instead of inputting a single static value, curve numbers are automatically determined by the model utilizing input parameters of soil hydrologic group, crop type, conservation practice, tillage system, and daily updated surface crop residue amounts (Rawls et al. 1980). The procedure for determining an "s" retention value for calculating runoff volume has been modified to reflect daily changes in soil moisture conditions (Smith and Williams, 1980). The peak discharge rate continues to be calculated using the morphological-based empirical formula used in CREAMS (Smith and Williams, 1980) with new modifications to compensate for high discharge rates observed in AGNPS.

Sediment transport and deposition by particle class size is calculated utilizing the steady state continuity equation described by Foster et al. (1981) and Lane (1982). The method incorporates a depositional rate equation from Young et al. (1986) as well as a modified form of the Bagnold stream power equation (1966). Mannings equation is used to solve for channel flow velocity.

The chemical transport model (Frere et al., 1980) has remained unchanged except for the accounting of daily nutrient losses from plant uptake and mineralization. These procedures were also derived from Frere et al. (1980).

### Continuous Routines in ANN-AGNPS

#### Weather Generator

ANN-AGNPS incorporates a stochastic weather generator used by a number of other ARS erosion and water quality models. CLIGEN, described by Nicks and Lane (1989), is a separate model from ANN-AGNPS, generating daily weather parameters required by ANN-AGNPS to update key environmental variables. Daily weather parameter output of minimum and maximum air temperature, precipitation, solar radiation, and wind speed and direction are statistically estimated from a national data set of average monthly records. A daily erosivity value describing total storm energy multiplied by the maximum 30 minute intensity is calculated from storm duration and the time to the storm's maximum intensity.

#### Soils

The ANN-AGNPS soils data base is derived from the SCS SOILS 5 data base. Soil data are processed through initial calculations to derive specific information describing soil physical characteristics which are then continually updated to reflect changing environmental conditions. ANN-AGNPS incorporates many of the WEPP procedures for estimating baseline parameter values for soil bulk density, porosity, saturated hydraulic conductivity, field capacity and wilting point (Lane and Nearing, 1989).

ANN-AGNPS determines the amount of water available for infiltration by subtracting calculated runoff from precipitation. Moisture is then percolated from soil layer to soil layer whenever soil field capacity is exceeded in a layer. The percolation rate is determined using a linear storage routing function which modifies conductivity from a saturated conductivity value near soil saturation to 0 at field capacity (Savabi et al. 1989).

Soil moisture is modified daily due to percolation, soil evaporation and plant transpiration. Richie's ET model (1972) is the basic evapotranspiration component used in ANN-AGNPS. Evapotranspiration, leaf area index, and soil texture characteristics are used to determine an evaporation rate. Plant transpiration values also incorporate the evapotranspiration rate, leaf area index, a water use rate-depth parameter, root depth and soil moisture within the layers (Savabiet al. 1989).

Plant Growth and Residue Decomposition

The ANN-AGNPS model contains routines for simulating plant growth and decay. A simple heat unit index (HUI) accumulation procedure is used for growing the plant from planting date to a user input maximum plant maturity level (Williams et al. 1989). The biomass is then apportioned to above ground leaf and stems and below ground roots. The leaf area index is calculated incorporating updated biomass (Williams et al. 1984).

Residue that accumulates on the ground surface from leaf drop and harvest alters the hydraulics and erodibility of the soil. The rate of residue biomass decay is a function of accumulated weather and soil moisture conditions (Stroo et al. 1989). Field operations further modify the structure and location of residue which in turn influences decomposition rates.

Soil Erosion

Updating AGNPS from a single storm simulation to a multiple storm continuous simulation required selecting a new soil erosion model that would incorporate daily updated environmental parameter values. The Revised USLE, or RUSLE, was selected because of its enhanced capacity to calculate erosion on a 15 day continuous basis. ANN-AGNPS utilizes several RUSLE routines on a daily basis, calculating erosion whenever a rain event occurs.

The basic structure of RUSLE is the same as the USLE. The 5 USLE factors: R, K, LS, C, and P, are determined and then multiplied together for estimating rill and sheet erosion. The methods for deriving each RUSLE factor involve utilizing equations simulating temporal changes in the environment which alter physical processes affecting erosion (Renard et al. in press). This new capability, however, requires the use of a computer model to carry out the calculations.

C Factor

The RUSLE and ANN-AGNPS C-factor calculations are the most detailed and most necessary to have accurately representing the physical processes. Through the selection of management practices and the subsequent changes in environmental parameters, the user is capable of interacting with the model and testing the impact of alternative field management scenarios. Management and cropping impacts on erosion rates within ANN-AGNPS are represented through the soil loss ratio (SLR). SLR values are reflective of daily field condition changes brought about by a particular management practice and modified by weather conditions. The SLR itself is derived from a number of subfactors (Yoder, et al. in press):

$$SLR = PLU * CC * SC * SR \qquad (1)$$

where PLU is the prior land use subfactor, CC is the canopy cover subfactor, SC is the surface cover subfactor, and SR is the surface roughness.

Prior land use reflects the impact of subsurface residue from previous crops and the effect of previous tillage practices on soil consolidation. ANN-AGNPS accounts for daily changes in biomass, needed for the determination of the PLU subfactor.

The canopy cover subfactor represents the ability of crop cover to protect the soil surface from the erosive powers of raindrops. Through the growing season and including senescence, ANN-AGNPS keeps track of the fraction of land surface covered by canopy and the height of the canopy, the two plant growth parameters needed to determine the value of CC subfactor.

Surface cover influences erosion rates by reducing the transport capacity of water flowing over the soil surface by creating mini-barriers. It also protects the soil from raindrop impact. The parameters used to determine the surface cover subfactor are the current soil surface roughness, the percentage of land area covered by surface cover, and the effectiveness of surface cover in reducing soil erosion. The first two parameters are tracked by ANN-AGNPS and the third is a constant value in the model.

The surface roughness subfactor represents the roughness of the surface and its ability to dampen soil erosion. Soils that have been tilled contain depressions and barriers which inhibit the flow of water and the transport of sediments. Daily values of surface roughness decrease as a function of time and rainfall. ANN-AGNPS accounts for this decrease in the same way as RUSLE, with a function relating the net roughness following a field operation and a decay coefficient based on the accumulated rainfall amount since the last operation.

Utilizing the spreadsheet interface, the ANN-AGNPS user records the day a field operation takes place and the particular implement utilized. Based upon this information and the generated weather data, the model retrieves the needed parameters from the management operations data base.

LS Factor

ANN-AGNPS calculates a RUSLE LS factor for both single-segmented and complex, multiple-segmented slopes. The RUSLE LS calculation includes calculating slope steepness and slope length subfactors and combining them into a single LS value. The slope length value is modified based upon the susceptibility of the soil to rill and interrill erosion (McCool et al. in press).

P Factor

ANN-AGNPS calculates a P factor based upon the type of conservation - terraces, strip-cropping or contours. A P value is calculated once per growing year and is based upon how the placement or configuration of the practice relative to the hillslope affects the hydraulics of the hillslope, which in turn impacts the sediment transport capacity of runoff. The impact of previous cropping practices on surface roughness is also included when determining P values for strip-cropping (Foster et al., in press).

R Factor

The erosivity capacity of rainfall is determined by the CLIGEN program. A rainstorm duration and a time to peak rainfall intensity are used to calculate a per-storm intensity value which is used in the basic RUSLE equation whenever a rain event occurs.

K Factor

At present, ANN-AGNPS does not incorporate a time variable K factor. The K factor is loaded into the program from the soils data base and kept constant throughout the program.

## MODEL INPUT AND OUTPUT

ANN-AGNPS has in some ways simplified data input to the model and at the same time required more detail. The extra detail comes not in defining particular parameter values, but rather in describing the type and timing of field management practices. ANN-AGNPS requires the same structural information needed in AGNPS for defining the watershed shape, size and the direction of flow within the watershed, including cell size, the number of the cell into which a cell drains (receiving cell number), and the cell flow direction.

Similar to AGNPS, ANN-AGNPS requires information on channels located within each cell, specifically the channel shape, channel slope, channel side slope, the length of the channel within the cell and Mannings' roughness coefficient.

Data entry for hillside topographic data has been expanded to enable input of multiple segmented slopes. Information required for both a single and multiple segmented slope include slope length, percent slope, and slope aspect.

ANN-AGNPS requires more detailed information on soil parameters. This soil information is accessed from the model's soils data base. The user is required only to select a state and county containing the watershed and then choose the dominant soil mapping unit for each cell. Soils information contained in the data base consists of the number of soil layers, depth of each layer, soil surface albedo, K factor, hydrologic group, and percent clay sand, rock fragments, organic matter, and cation exchange for each layer. If updates to the soil data are needed, the user can enter new values, and save the soil information under a new name.

Entering information for a particular cell's management practice requires the greatest number of inputs from the user. The user has to create a management scenario for each different set of field operations represented by a watershed grid cell. These scenarios may represent either actual practices or hypothetical conservation scenarios to be tested. The management input screen prompts the user for the number of crops per rotation and the type and order of crops in the rotation. Information on conservation management practices is prompted if they exist for a management scenario. Four different conservation practices can be applied (1) contours, (2) strip cropping, (3) terraces and (4) filter strips. Specific information describing the size, placement and orientation of these practices is requested.

The user then enters the type and date of field operations taking place within a rotation. Field operations are divided into tillage (soil disturbance), planting, harvest/cutting and fertilizing. The program requires the user to choose specific implements, fertilizer rates for both N and P, a fertilizer availability factor, and either a harvest amount in bushels or a remaining residue cover in either percent or lbs/acre. Management scenarios are saved in the management data base. A particular scenario can be copied to any other cell and used in its original form or altered to create a new scenario.

## MODEL TESTING

The first preliminary test of ANN-AGNPS is being carried out on a monitored watershed south of Morris, Minnesota. The watershed is 1087 acres in size, with 1063 acres in cropland, 13 acres in woodlots, 8 acres in farmstead, and 3 acres in pasture. Cropland is broken down into 633 acres of corn, 235 acres of soybeans, 184 acres of small grain and 11 acres of set-aside fallow.

The dominant soil in the watershed is a Barnes-Buse Loam complex with approximately 70% Barnes and 30 % Buse. Both are deep, well drained soils located on gently rolling to hilly landscapes. The majority of the watershed is relatively flat and gently sloping, with slopes ranging from 0 - 3 %. The upper reaches of the watershed are somewhat steeper ranging from 3 - 5 % slope and dissected by short steeper slopes ranging from 6 - 7 %.

The watershed is entirely surface-drained through naturally occurring depressions and channels. Within some fields a buffer-strip has been left a few meters on each side of the channel, while in other fields the channel is tilled through. Channel width for those with definite form ranges from 1 to 3 meters, increasing in width down slope. Slopes of channels vary with land slope, ranging from 3 - 4 % in the uplands to near 0 - 3 % in the lower areas of the watershed.

The watershed was divided into 28 forty acre grid cells and data was collected from locally available sources and entered into the model's spread sheet. Data collection was facilitated by using a Geographic Information System in calculating flow directions and land slope, as well as determining which field and soil constituted the majority area within the cell. Additional field checking was required to gather data on channel characteristics and to validate values generated by the GIS.

Model Results

The watershed was monitored during the 1992 growing season. Data was collected for only 1 major storm episode consisting of several closely occurring rain storms with one major event.

| Date | Rainfall inches | Runoff Volume inches | | Peak Discharge cfs | | Sediment Yield tons | |
|---|---|---|---|---|---|---|---|
| | | obs | pred | obs | pred | obs | pred |
| 6/16-6/17 | 2.69 | 0.60 | 0.65 | 46.8 | 40.8 | 16.97 | 28.65 |

Table 1. Summary of observed and predicted watershed response.

ANN-AGNPS simulated the one storm reasonably well. As can be observed, a large percentage of rainfall ended up as watershed runoff. The model's ability to account for antecedent soil moisture conditions perhaps helps the model to estimate runoff more accurately then if a single curve number value was required for the storm of interest. For this storm, sediment yield was over predicted by 68%. This may be due to inadequate accounting for the filtering effects of vegetation along several of the channels, as they affect upland eroded sediments entering laterally into these channels. This could possibly be corrected by subdividing some cells to more accuratley represent the filter strips along the channels.

One rainstorm obviously does not constitute a sufficient set of observations from which to assess the accuracy of the model. Also, nutrient observations were not included in this preliminary analysis. Since sediment is but one source of agricultural pollutants, a model that is to be used for the WQPP must also account for nutrients as well as pesticides. Continued validation will take place, looking at both sediment and agricultural chemical yields, using additional data sets from around the country.

## CONCLUSIONS

Expanding AGNPS beyond a single event model has added considerable capacity to the model. ANN-AGNPS is better capable of accounting for temporal variations which greatly influence the generation and transport of agricultural pollutants. This accountability will result in better estimations of sediment and nutrient loading from the watershed. Another advantage of the continuous model is the ability of the user to interact with the model on a more direct and familiar level. Instead of inputting estimated coefficient values representing a particular antecedent condition, the model user can input the timing of the practice and the type of implement used. The true utility of ANN-AGNPS will be in its ability to generate alternative management scenarios and easily re-locate those practices around a watershed to evaluate changes in pollutant loadings.

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