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Economics, Ethics, Ecology: Roots of Productive Conservation

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CREAMS: A System for Evaluating Best Management Practices

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Mathematical models to assess nonpoint-source pollution and evaluate the effects of management practices are needed to respond adequately to the water quality legislation of the past 10 years. Action agencies must assess nonpoint-source pollution from agricultural areas, identify problem areas, and develop conservation practices to reduce or minimize sediment and chemical losses from fields where potential problems exist. Monitoring every field or farm to measure pollutant movement is impossible, and landowners need to know benefits before they apply conservation practices. Only through the use of models can pollutant movement be assessed and conservation practices most effectively planned.

In 1978 the U.S. Department of Agriculture's Science and Education Administration—Agricultural Research began a national project to develop relatively simple, computer-efficient mathematical models for evaluating nonpoint-source pollution. A model that does not require calibration was planned because little data suitable for calibrating a model were available. Initial efforts concentrated on a field scale because that is where conservation management systems are applied. A field was defined as an area with a relatively homogeneous soil under a single management practice and small enough so that rainfall variability was minimal. Requirements for the model were that it be simple and yet represent a complex system, be physically based and not require calibration, be a continuous simulation model, and have the potential to estimate runoff, erosion, and transport of chemicals in solution and attached to the sediment. The result of this project was CREAMS, a field-scale model capable of assessing these conditions and meeting these requirements (*14*).

Our purpose here is to present the concepts, to describe briefly each component of the model, and to describe an application of CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems). A complete description of the model and instructions for its use have been published by the U.S. Department of Agriculture (*14*).

Model development

Simple mathematical expressions have been used for years as models in hydrology, erosion, and sedimentation. The universal soil loss equation (USLE) is a simple mathematical model that relates average annual soil loss (A) to an average annual rainfall erosivity factor (R), a soil erodibility factor (K), a slope length and steepness factor (LS), a cover-management factor (C), and a supporting practice factor (P) in the form A = RKLSCP (*17*). The USLE is a much-used and powerful model for estimating long-term erosion. Values for its factors are readily available, and calculations are quick and easy. Values for the C and P factors can be changed to represent different management and cover conditions, and model calculations can be repeated to estimate the influence of a change in management.

With present-day needs for evaluating runoff, percolation, erosion/sediment transport, and associated dissolved and sediment-adsorbed chemical losses from farms, one simple relationship is insufficient. Also, long-term averages can be meaningless, as in the case of a toxic pesticide that may only be a problem for a few days after application. Interactions between the various components of the transport system prevent the use of single, straightforward calculations. However, the physical processes can be represented by a logical series of mathematical expressions that can be solved repetitively and easily with high-speed computers. First, the modeler identifies the important physical processes that must be represented to provide the accuracy and detail of information needed from the model. Formulation of the model expresses the modeler's concepts of the physical system and ideas of the order of processes. Computer efficiency is also important, especially when a model is to be used many times to evaluate a system as complex as that in nonpoint-source pollution. If a model is to show effects of management practices, the necessary equations and parameters that reflect the practices must be incorporated into the model.

Models are developed for specific purposes. Their application outside these specific conditions can result in erroneous answers. For example, use of a model for estimating streamflow from large basins would likely give misleading estimates of runoff from a five-acre area. Average infiltration might be satisfactory for the basin scale, but for the field scale temporal and spatial variations in infiltration might be important. Sediment yield estimates for large basins often require careful description of channel processes, whereas accurate descriptions of erosion by raindrop impact on overland flow areas may be most important for estimating sediment yield from fields.

Review of models

Passage of the Federal Water Pollution Control Act Amendments, Public Law 92-500, in 1972 resulted in the need for mathematical models to evaluate pollution from diffuse agricultural areas. These needs resulted in a proliferation of model development. Although hydrology and erosion models were available, there were few models for chemical transport. Models for evaluating nonpoint-source pollution were assembled, oftentimes by "piggy-backing" erosion and chemical components onto hydrology models for both field-size and basin-size areas.

Crawford and Donigian (*3*) developed the pesticide runoff transport (PRT) model to estimate runoff, erosion, and pesticide losses from field-size areas. The hydrologic component of the PRT model is the Stanford watershed model (*4*); the erosion component was developed by Negev (*11*). The Stanford watershed model was among the first computer simulation models developed for basin-size areas.

Donigian and Crawford (*5*) incorporated a plant nutrient component with the basic PRT model to develop the agricultural runoff model (ARM). The hydrology, erosion, and pesticide components are the same as the PRT model. ARM is also for field-size areas. Both the PRT and ARM models require data for calibration.

Frere and associates (*7*) developed an agricultural chemical transport model (ACTMO) to estimate runoff, sediment yield, and plant nutrients from field- and basin-size areas. The hydrologic component is the USDA Hydrograph Lab model (*9*), which is based on an infiltration concept. The erosion component is based on the rill and inter-rill erosion concepts and USLE modifications developed by Foster and colleagues (*6*). The ACTMO model does not require calibration.

Bruce and associates (*2*) developed an event model—WASCH—to estimate runoff, erosion, and pesticide losses from field-size areas for single runoff-producing storms. The model requires calibration to a specific site.

Beasley and colleages (*1*) developed the ANSWERS mode to estimate runoff, erosion, and sediment transport from basin-size areas. The model does not have a chemical component. It is used to identify sources of erosion and areas of deposition within a basin.

The ARM, WASCH, and ANSWERS models are expensive to operate and cannot be used economically for long-term simulation. Long-term simulation and risk analysis are desirable for examining probabilities of exceeding toxic pesticide concentrations.

Models that require calibration to evaluate parameter values are generally calibrated for a specific site and practice. If relationships for the physical processes are not carefully formulated, parameter values can be seriously distorted. Calibration of a model with data for a specific site and management practice can give erroneous results when the model is applied to a different site or management practice without recalibration. Minimizing the need for calibration is desirable. A model is most useful when values for its parameters are readily available as functions of easily measured features of the evaluated site and practice. Both modelers and model users should be aware of problems associated with calibration, availability of parameter values, parameter distortion by inadequate watershed representation, inaccurate results from poorly formulated equations, and excessive use of computer time. We sought to minimize these problems with CREAMS.

CREAMS model structure

CREAMS consists of three major components: hydrology, erosion/sedimentation, and chemistry. The hydrology component estimates runoff volume and peak rate, infiltration, evapotranspiraton, soil water content, and percolation on a daily basis. If detailed precipitation data are available, the model calculates infiltration at histogram breakpoints. The erosion component estimates erosion and sediment yield, including particle distribution at the edge of the field on a daily basis. The chemistry component includes elements for plant nutrients and pesticides. Stormloads and average concen-

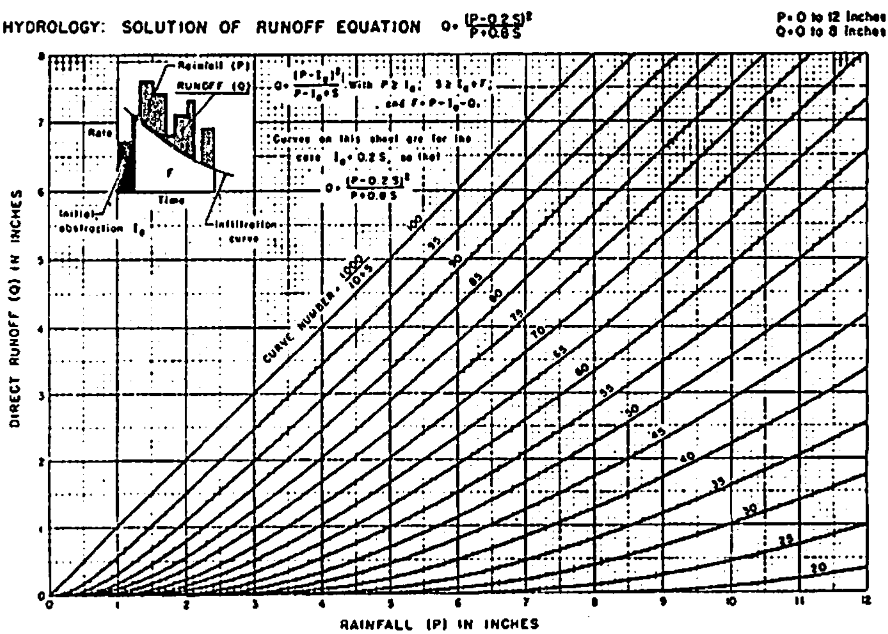

Figure 1. Soil Conservation Service curve number method of storm runoff estimation (*15*).

trations of adsorbed chemicals and dissolved chemicals in the runoff, sed ment, and percolate fractions are estimated.

The hydrologic component. The hydrologic component consists of tw options, depending upon availability of rainfall data. One option estimate storm runoff when only daily rainfall data are available. If hourly or break point (time-intensity) rainfall data are available, a second option estimate storm runoff by an infiltration-based method.

Option 1: Williams and LaSeur (*16*) adapted the Soil Conservation Ser vice (SCS) curve number method (*15*) for simulation of daily runoff. Th method relates direct runoff to daily rainfall as a function of curve numbe (Figure 1). Curve number is a function of soil type, cover, managemen practice, and antecedent rainfall. The relationship of runoff, Q, to rainfall P, is

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad [1$$

where S is a retention parameter related to soil moisture and curve number An equation for water balance is used to estimate soil moisture from:

$$SM_t = SM + P - Q - ET - O \qquad [2$$

where SM is initial soil moisture, SM_t is soil moisture at day t, P is precipita tion, Q is runoff, ET is evapotranspiration, and O is percolation below th root zone.

The percolate component uses a storage routing technique to estimat flow through the root zone. The root zone is divided into seven layers. Th first layer is 1/36 of the root zone depth, the second layer 5/36 of the tota depth, and the remaining layers, all equal in thickness, are 1/6 of the roo zone depth. The top layer is approximately equal to the chemically activ surface layer and the layer where inter-rill erosion occurs. Percolation fron a layer occurs when soil moisture exceeds field capacity. Amount o percolation depends on saturated hydraulic conductivity.

The peak rate of runoff, q_p, (required in the erosion model) is estimatec by the empirical relationship

$$q_p = 200\, D^{0.7}\, C^{0.159}\, Q^{(0.917 D^{0.0166})}\, L^{-0.187} \qquad [3$$

where D is drainage area, C is mainstem channel slope, Q is daily runof volume, and L is the watershed length-width ratio (*14*). Although equatior 3 was developed and tested for basin-size areas, testing of CREAMS ha shown it to be applicable to field-size areas as well.

Option 2: The infiltration model is based on the Green and Ampt equation (*8, 13*). The concept defined in figure 2 assumes some soil water initially in a surface infiltration-control layer. When rainfall begins, the soil water content in the control layer approaches saturation and surface ponding occurs at a time, t_p (Figure 2). The amount of rain that has infiltrated by the time of ponding, designated F_p in figure 2, is analogous to initial abstraction in the SCS curve number model (option 1), but is also a function of rainfall intensity. After the time of ponding, water is assumed to move downward as a sharply defined wetting front with a characteristic capillary tension as the principle driving force. The infiltration curve of figure 2 is approximated to give the infiltrated depth, ΔF, in a time interval, Δt, as

$$\Delta F = [4A(GD + F) + (F - A)^2]^{1/2} + A - F, \qquad [4]$$

where $A = K_{si}t_i/2$, $D = \Theta_s - \Theta_i$, Θ_s is water content at saturation, Θ_i is initial water content, G is the effective capillary tension of the soil, and K_s is the effective saturated conductivity. The average infiltration rate $\bar{f}_i$ for the ith interval is

$$\bar{f}_i = \frac{\Delta F_i}{\Delta t_i} \qquad [5]$$

and runoff/rainfall excess, q_i, during the interval is rainfall rate for the interval minus the infiltration rate, $r_i - \bar{f}_i$. Total runoff is the sum of all q_i for the storm. The infiltration-based model has three parameters: G, D, and K_s.

Percolation is estimated as in option 1, except that a single layer below the infiltration control layer represents the root zone. Percolation is calculated using average profile soil water content above field capacity and the saturated hydraulic conductivity, K_s. Peak rate of runoff is estimated by attenuating the rainfall excess using the kinematic wave model with parameter values to account for nonuniform steepness and roughness along the slope (*18*).

The evapotranspiration (ET) element of the hydrologic component is the

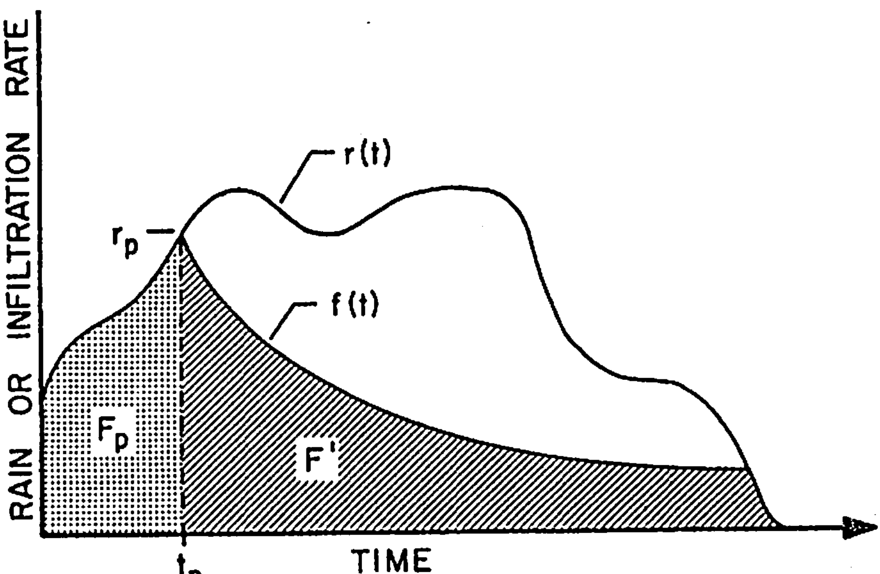

Figure 2. Schematic representation of runoff model using infiltration approach (*13*).

same for both options. The ET model, developed by Ritchie (*12*), calculates soil and plant evaporation separately. Evaporation, based on heat flux, is a function of daily net solar radiation and mean daily temperature, which are interpolated from a Fourier series fitted to mean monthly radiation and temperature (*10*). Soil evaporation is calculated in two stages. In the first, soil evaporation is limited only by available energy and is equal to potential soil evaporation. In the second, evaporation depends upon transmission of water through the soil profile to the surface and time since stage two began. Plant evaporation is computed as a function of soil evaporation and leaf area index. If soil water is limiting, plant evaporation is reduced by a fraction of the available soil water. Evapotranspiration, which is the sum of plant and soil evaporation, cannot exceed potential soil evaporation.

The erosion component. The erosion component considers the basic processes of soil detachment, transport, and deposition. The concepts of the model are that sediment load is controlled by the lesser of transport capacity or the amount of sediment available for transport. If sediment load is less than transport capacity, detachment by flow may occur, whereas deposition occurs if sediment load exceeds transport capacity. Raindrop impact is assumed to detach particles regardless of whether or not sediment is being detached or deposited by flow. The model represents a field comprehensively by considering overland flow over complex slope shapes, concentrated channel flow, and small impoundments or ponds (Figure 3). The model estimates the distribution of sediment particles transported as primary particles—sand, silt, and clay—and large and small aggregates that are conglomerates of primary particles. Sediment sorting during deposition and consequent enrichment of the sediment in fine particles is calculated.

Detachment is described by a modification of the USLE for a single storm event (*6*). Rate of inter-rill detachment, D_{IR}, in the overland flow element is expressed as

$$D_{IR} = 0.210\,EI\,(S_{of} + 0.014)\,KCP\,(q_p/Q) \qquad [6]$$

where EI is the product of a storm's energy and maximum 30-minute intensity, S_{of} is the slope of the land surface, q_p is peak runoff rate, Q is runoff volume, K is a soil erodibility factor, C is a cover-management factor, and P is a contouring factor. Rate of detachment, D_R, by rill erosion is expressed as

$$D_R = 37983\,nq_p^{4/3}(x/72.6)^{n-1}\,(S_{of})^2\,KCP \qquad [7]$$

where x is the distance downslope and n is a slope-length exponent. The factors K, C, and P are from the USLE. Inter-rill erosion is primarily a function of raindrop impact on areas in between the rills; it is not a function of runoff as the term q_p/Q suggests in equation 6. This term converts total erosion for the storm to an average rate. Rill erosion is a function of runoff rate. Sediment transport capacity for overland flow is estimated by the Yalin transport equation (*19*), modified for nonuniform sediment having a mixture of sizes and densities.

The concentrated flow or channel element of the erosion model assumes that the peak runoff rate is the characteristic discharge for the channel. Calculation of detachment or deposition and transport of sediment are based on this discharge. Discharge is assumed to be steady but spatially varied, increasing downstream from lateral inflow. Friction slope of the flow is estimated from regression equations fitted to solutions of the spatially varied flow equations so that drawdown or backwater from a control at the channel outlet can be considered.

Detachment can occur when sediment load is less than transport capacity of the flow and shear stress of the flow is greater than the critical shear

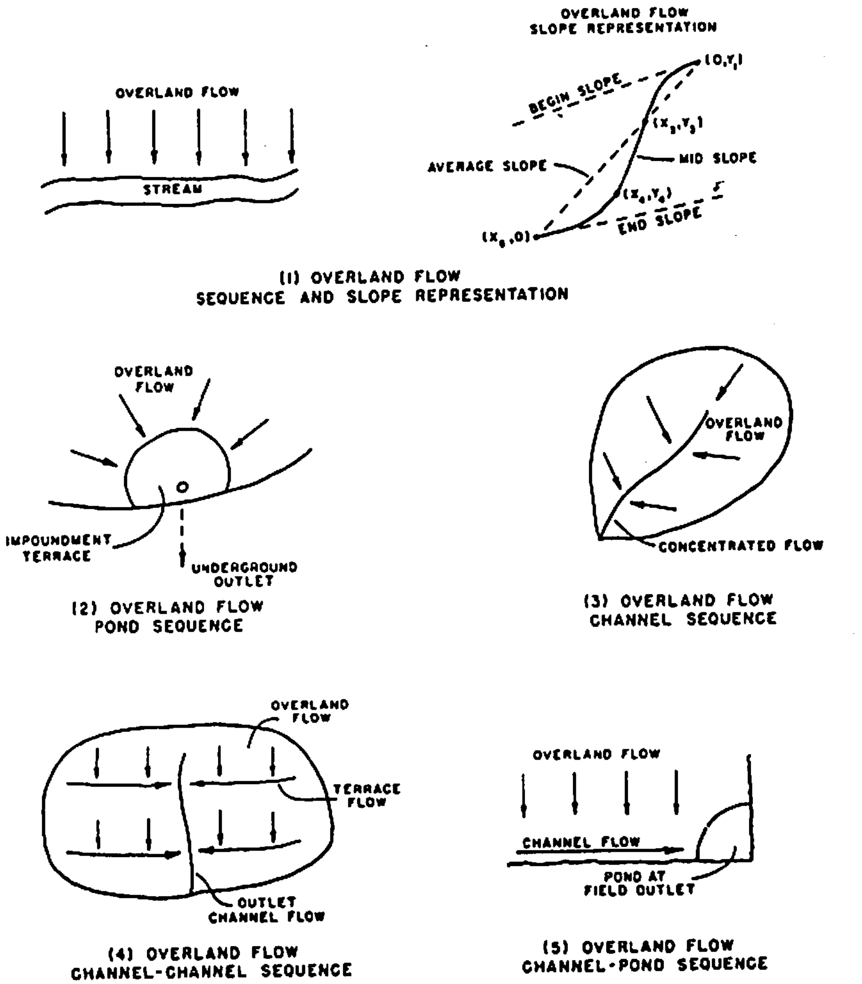

Figure 3. Schematic representation of typical field systems in the field-scale erosion/sediment yield model.

stress for the soil in the channel. Both bare and grassed waterways, combinations of bare and grassed channels, and variable slope along the channel can be considered.

Water is often impounded in fields, either as normal ponding from a restriction at a fence line, a road culvert, a natural pothole, or in an impoundment-type terrace. These restrictions reduce flow velocity, causing coarse-grained primary particles and aggregates to be deposited. Deposition depends upon whether fall velocity of the particles causes the sediment to reach the impoundment bottom before flow carries them from the impoundment. The fraction of particles passing through the impoundment, FP, of a given particle class, i, is given by the exponential relation

$$FP_i = A_i e^{B_i d_i} \qquad [8]$$

where d_i is the equivalent sand-grain diameter and A_i and B_i are coefficients that depend upon impoundment geometry, inflow volume, infiltration through the impoundment boundary, and discharge rate from the impoundment.

In addition to calculating the sediment transport fraction for each of five particle classes, the model computes a sediment enrichment ratio based on specific surface area of the sediment and organic matter and the specific surface area for the residual soil. As sediment is deposited, organic matter, clay, and silt are the principle particles transported. This results in high enrichment ratios. Enrichment ratios are important in transport of chemicals associated with sediment.

Chemistry component—plant nutrients. The basic concepts of the nutrient component are that nitrogen and phosphorus attached to soil particles are lost with sediment yield; soluble nitrogen and phosphorus are lost with surface runoff; and soil nitrate is lost by leaching from percolation, by denitrification, or by extraction by plants.

The nutrient component assumes that an arbitrary surface layer 1/2 inch deep is effective in chemical transfer to sediment and runoff. All broadcast fertilizer is added to the active surface layer, whereas only a fraction is added by fertilizer incorporated in the soil; the rest is added to the root zone. Nitrate in the rainfall contributes to the soluble nitrogen in the surface layer.

Soluble nitrogen and phosphorus are assumed to be thoroughly mixed with the soil water in the active surface layer. This includes soluble forms from the soil, surface-applied fertilizers, and plant residues. The imperfect extraction of these soluble nutrients by overland flow and infiltration is expressed by an empirical extraction coefficient. The amounts of nitrogen and phosphorus lost with sediment are functions of sediment yield, enrichment ratio, and the chemical concentration of the sediment phase.

When infiltrated rainfall saturates the active surface layer, soluble nitrogen moves into the root zone. Incorporated fertilizer, mineralization of organic matter, and soluble nitrogen in rainfall percolated through the active surface layer increase the nitrate content in the root zone. Uniform mixing of nitrate in soil water in the root zone is assumed. Mineralization is calculated by a first-order rate equation from the amount of potential mineralizable nitrogen, soil water content, and temperature. Optimum rates of mineralization occur at a soil temperature of 35 °C. Soil temperature is estimated from air temperature in the hydrologic component.

Nitrate is lost from the root zone by plant uptake, leaching, and denitrification. Plant uptake of nitrogen under ideal conditions is described by a normal probability curve. The potential uptake is reduced to an actual value by a ratio of actual plant evaporation to potential plant evaporation. A second option for estimating nitrogen uptake is based on plant growth and the plant's nitrogen content.

The amount of nitrate leached is a function of the amount of water percolated out of the root zone, estimated by the hydrologic component and the concentration of nitrate in the soil water. Denitrification occurs when the soil water content exceeds field capacity. The rate constant for denitrification is calculated from the soil's organic carbon content; it is adjusted by a twofold reduction for each 10-degree decline in temperature from 35 °C.

The plant nutrient component thus estimates nitrogen and phosphorus losses in sediment, soluble nitrogen and phosphorus in the runoff, and changes in the soil's nitrate content due to mineralization, uptake by the crop, leaching by percolation through the root zone, and denitrification in the root zone for each storm. Nitrogen and phosphorus concentrations in runoff and sediment are computed. Individual storm losses are accumulated for annual summaries that are used to compute average concentrations.

Pesticides. The pesticide component estimates concentration of pesticides in runoff (water and sediment) and total mass carried from the field for each storm during the period of interest. The model accommodates up to 10 pesticides simultaneously in a simulation period. Foliar-applied pesticides are considered separately from soil-applied pesticides because degradation of pesticides is more rapid on foliage than in soil. The model considers multiple applications of the same chemical, such as insecticides. Figure 4 is a flow chart of the pesticide component.

As in the plant nutrient component, an active surface layer about 1/2 inch deep is assumed. Movement of pesticides from the surface is a function of runoff, infiltration, and pesticide mobility parameters. Pesticide in runoff is partitioned between the solution phase and the sediment phase by the following relationships:

$$(C_w Q) + (C_s M) = a\, C_p \qquad [9]$$

and

$$C_s = K_d\, C_w \qquad [10]$$

where C_w is pesticide concentration in runoff water, Q is volume of water per unit volume of surface active layer, C_s is pesticide concentration in sedi-

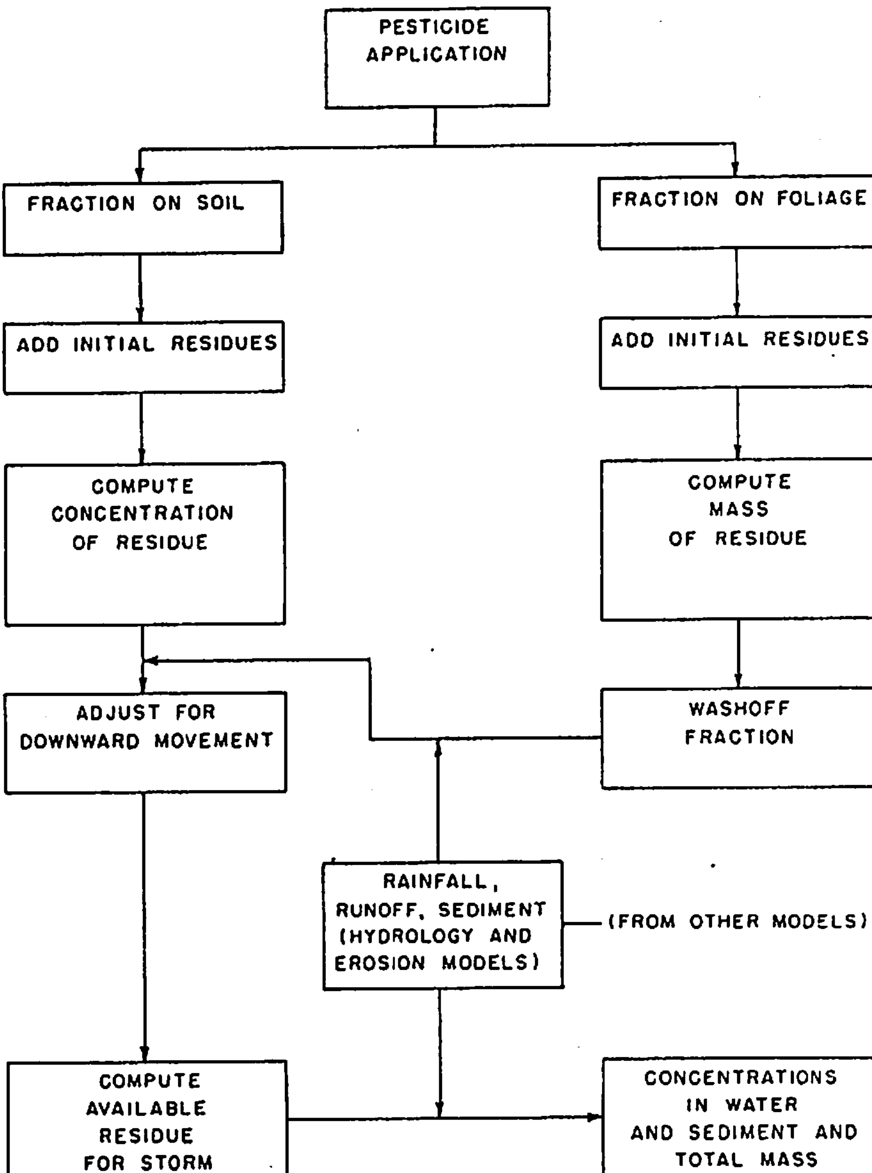

Figure 4. Simplified schematic representation of the pesticide model.

ment, M is mass of soil per unit volume of active surface layer, a is the extraction ratio of the concentration of pesticide extracted by runoff to the concentration of pesticide residue in the soil, C_p is the concentration of pesticide residue in the soil, and K_d is the coefficient for partitioning the pesticide between sediment and water phases. The concentration, C_w, of the pesticide in solution in runoff from the field is less than the soluble concentration in the surface layer because of inefficient extraction by runoff. The pesticide concentration, C_s, is that in the soil material of the surface layer. Selective deposition, as expressed by enrichment ratio, enriches this concentration in the sediment leaving the fields. The amount of pesticide attached to the sediment leaving the field is the product of the concentration C_s, sediment yield, and enrichment ratio.

Pesticide washed off foliage by rain increases the residual pesticide concentration in the soil. The amount calculated as available for washoff is updated between storms by a foliar degradation process. Pesticide residue in the surface layer is reduced by imperfect extractions by overland flow and infiltrated rainwater and by degradation described by an exponential function with a half-life parameter.

Application of CREAMS

A major use of CREAMS is evaluation of alternate management practices for control or minimization of runoff of sediment and chemicals. Several alternate practices might be proposed for a given site. Each could be

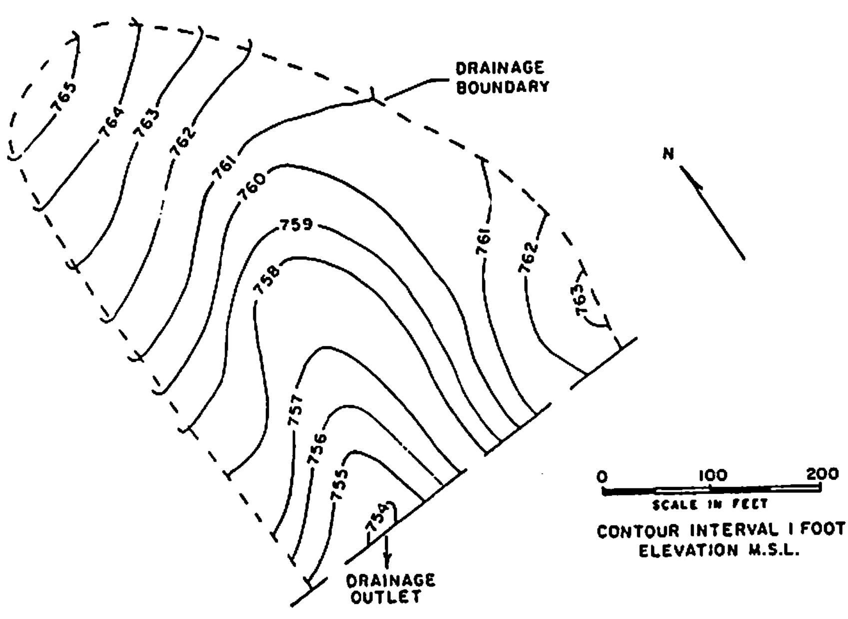

Figure 5. Topographic map for the Georgia Piedmont field.

Table 1. Hydrologic analysis of several farming practices for the example Georgia watershed. Values are from CREAMS simulations.

Management Practice	Rainfall* (in)	Runoff (in)	Percolation (in)	Evapotranspiration (in)	Product† Q (q_p) Total	Average/Event
1	116	14.4	24.3	78.4	38.7	0.74
2	116	14.4	24.3	78.4	38.7	0.74
3	116	8.9	29.2	78.8	22.1	0.61
4	116	8.9	29.2	78.8	19.7	0.55
5	116	14.5	24.4	78.4	38.7	0.74

*Total for the period May 1973-October 1975.
†Product of runoff volume, Q, and runoff peak rate, q_p (in^2/hr).

evaluated with CREAMS, and a farmer could select a practice from those judged satisfactory.

Example area and practices. A 3.2-acre area from the Georgia Piedmont physiographic area illustrates the application of CREAMS. Figure 5 shows the topography of the field. The fenceline restricts surface drainage, which results in temporary ponding of runoff. The soil is a Cecil sandy loam, 24 inches deep to the B2 horizon.

Five management practices were analyzed for continuous corn:

Practice 1. Conventional tillage—moldboard plow in the spring, disk twice, plant, and cultivate twice. Rows run across the drainage, more or less on the contour in the upper end of the field and generally up-and-down slope at the lower end. Runoff is restricted at the fenceline.

Practice 2. Same as practice 1, except with a grassed waterway in the concentrated-flow area.

Practice 3. Chisel plow is used instead of moldboard and no cultivation; grassed waterway is used in the concentrated-flow area.

Practice 4. Conventional tillage, same as practice 1; channel-type terraces with 0.2 percent grade; tillage on contour; grassed terrace outlet channel.

Practice 5. Same as practice 1 with a tile outlet impoundment at the fenceline.

The plant nutrient component was run twice, once with practice 1 for a single application of 125 pounds per acre nitrogen and 25 pounds per acre phosphorus at planting time and again with a split application of nitrogen—25 pounds per acre incorporated at planting time and 100 pounds per acre topdressed 30 days after planting. A soluble pesticide, atrazine, and one adsorbed type, paraquat, were assumed to be surface-applied at planting time at the rate of 3.0 pounds per acre and 1.83 pounds per acre, respectively, for each management practice. Paraquat used in this application is considered only as an indicator for transport of any strongly soil-adsorbed chemical that is applied annually or is present as a residue from previous applications.

Results from hydrologic component. The daily rainfall hydrologic option was used to generate hydrologic values required by the erosion and chemistry components. Table 1 shows the results. Hydrologically, the only changes were in management practices 3 and 4 as compared with practice 1. Reduced curve numbers resulted in less computed runoff for these two practices. The roughness and the surface cover of corn residue in the chisel plow system accounted for its reduction in runoff. In practice 4, terraces and contouring reduced runoff volume and attenuated the peak rate of runoff because of a longer total flow path (increased effective length:width ratio). The parameters were not chosen to reflect a hydrologic influence of the grassed waterway or impoundment at the fenceline.

The effect of terraces and contouring on runoff was equal to that of chiseling and associated crop residue. Runoff volume and thus percolation and evapotranspiration did not change between practices 3 and 4. Runoff, percolation, and evapotranspiration were the same for practices 1, 2, and 5. However, runoff from these practices was 1.6 times that from practices 3 and 4.

The last column of table 1 gives the sum of the product of volume of runoff and peak runoff rate for the period of record, which is an index of the potential power of runoff for sediment transport. The index provides a relative comparison of the management practices. Since runoff volumes and peak rates did not change among practices 1, 2, and 5, the index value did not change. The peaks associated with lower volumes for practice 3 resulted in a much lower value, and the peak attenuation caused by the terraces in practice 4 further reduced the index even though volumes were the same for practices 3 and 4. The empirical relationship for peak rate (equation 3) does not reflect an increased hydraulic roughness for grassed waterways, as in practice 2, or the effect of impoundments, as in practice 5.

Results from erosion/sediment yield component. To apply the erosion component, an overland flow element and a concentrated flow element were used to represent the watershed for practices 1, 2, and 3. An impoundment element was added for practice 5. Practice 4 was represented by an overland flow element and a series of two channel elements. Parameter val-

Table 2. Erosion/sediment yield analysis of several farming practices for the example Georgia watershed. Values are from CREAMS simulations.

Management Practice	Sediment Yield* (t/a)	Enrichment Ratio (ER) Based on Specific Surface Area	Product (SY•ER) (t/a)
1	9.47	2.1	19.89
2	4.80	2.7	12.96
3	1.79	2.3	4.12
4	1.72	2.9	4.99
5	0.96	4.3	4.13

*Total for the period May 1973-October 1975.

Table 3. Summaries of total plant nutrient components for five management practices for the Georgia Piedmont, 1973-1975. Values are from CREAMS simulations.

	Management Practice					
	1A*	1B	2	3	4	5
Nitrogen (lb/a)						
Inputs						
Fertilizer	375.0	375.0	375.0	375.0	375.0	375.0
Rainfall	21.1	21.1	21.1	21.1	21.1	21.1
Mineralization	65.0	65.0	65.0	65.3	65.3	65.9
Outputs						
Runoff	3.3	3.0	3.3	1.9	1.9	3.3
Sediment	33.7	33.7	19.7	8.2	7.8	4.8
Plant uptake	287.6	196.4	287.6	285.6	285.6	287.6
Leaching	51.9	94.9	51.9	61.2	61.2	51.9
Denitrification	95.8	182.7	95.8	91.6	91.6	95.8
Phosphorus (lb/a)						
Inputs						
Fertilizer	75.0		75.0	75.0	75.0	75.0
Outputs						
Runoff	1.2		1.2	.7	.7	1.2
Sediment	12.8		7.4	3.0	2.9	1.8

*Practices 1A, 2, 3, 4, and 5 had 25 pounds per acre of nitrogen fertilizer incorporated at planting and a topdressing of 100 pounds per acre about 30 days after corn emergence. Practice 1B had 125 pounds per acre incorporated at planting time.

ues for 10 overland flow paths around the watershed were averaged for a representative overland flow path. The fenceline at the watershed outlet was assumed to restrict flow, causing backwater.

Simulation results indicate the factors affecting erosion and sediment yield at this site (Table 2). Deposition occurred with practice 1 because the enrichment ratio, ER, of 2.1 was greater than 1.0. If the model computes no deposition, this ratio is 1.0. Deposition was on the toe of the concave overland flow slope, but most was in backwater immediately above the fenceline. The model predicted that the natural waterway upstream from the backwater would erode.

A grassed waterway, practice 2, eliminated erosion by concentrated flow in the previously unprotected waterway and caused deposition of some sediment eroded on the overland flow area. The increase in enrichment ratio from 2.1 to 2.7 resulted from increased deposition. Fines were not reduced in the same proportion as sediment yield (SY) because the enrichment ratio increased. The product of sediment yield and enrichment ratio, a relative measure of both sediment yield and specific surface area, indicates the carrying capacity for chemicals attached to the sediment.

Deposition in and at the edges of the grassed waterway would cause maintenance problems and should be reduced by reducing erosion on the overland flow area. Chisel plowing, practice 3, provided that reduction, which would also help maintain soil productivity.

Instead of conservation tillage, the farmer may prefer conventional tillage with conventional terraces, practice 4, and a grassed outlet channel. Sediment yield was reduced 82 percent, but the enrichment ratio increased because of considerable deposition in the terrace channels and in the grassed outlet channel. Another possibility was an impoundment terrace, practice 5, which further reduced sediment yield, but greatly increased the enrichment ratio. The resulting product of sediment yield and enrichment ratio was as high as that for practice 3, in which sediment yield was 1.8 times that of practice 5.

As expected, enrichment ratio increased as sediment yield decreased, but in a scattered fashion. Furthermore, the relationship may be quite different for other sites.

Results from nutrient component. Table 3 summarizes the results from the plant nutrient component for the 30-month period. Two runs were made for management practice 1 to demonstrate the effects of possible fertilizer treatments. Fertilizer application was the same for management practices 1A, 2, 3, 4, and 5, where 25 pounds per acre of nitrogen was incorporated at planting time and 100 pounds per acre of nitrogen was topdressed about 30 days after corn emergence. In practice 1B, 125 pounds per acre of nitrogen was incorporated at planting time.

The results for practices 1A, 2, 3, 4, and 5 reflect differences caused by changes in runoff and sediment yield for the different practices. Practices 3 and 4 resulted in less runoff and more percolation than did practices 1A, 3, and 5. Thus, nitrogen and phosphorus in runoff was less for practices 3 and 4, but more nitrate was leached out of the root zone, and more denitrification occurred. Plant uptake of nitrogen changed little because there was little change in evapotranspiration. These changes in nitrogen uptake reflect slightly different crop yields due to differences in water and nitrogen availability.

A split application versus a single application of nitrogen can be evaluated by comparing results for practices 1A and 1B. Part of the difference in nitrogen loss was due to storm rainfall/runoff/sediment loss events relative

Table 4. Summary of total pesticide losses for five management practices on the example Georgia watershed, 1973 to 1975. Values are from CREAMS simulations.

	Pesticide					
	Atrazine			Paraquat		
Management Practice	Total Applied (lb/a)	Total Loss (lb/a)	Percent of Application	Total Applied (lb/a)	Total Loss (lb/a)	Percent of Application
1	9.0	0.049	0.55	5.5	0.237	4.32
2	9.0	0.048	0.54	5.5	0.135	2.46
3	9.0	0.020	0.22	5.5	0.035	0.65
4	9.0	0.020	0.22	5.5	0.056	1.03
5	9.0	0.048	0.53	5.5	0.048	0.88

to time of application and part was due to all of the nitrogen being incorporated into the soil for practice 1B. Nitrogen uptake was less for the single application than for the split application for the same evapotranspiration because leaching and denitrification depleted the high soil nitrate following the single application. This illustrates the influence of storm sequence. If rainfall had been more frequent but less in total amount, the results might have been entirely different. Nitrate leaching among the five practices reflected the change in percolation. Surface losses of nitrogen and phosphorus largely reflected runoff and sediment losses.

Results from pesticide component. Table 4 summarizes pesticide losses for the five management practices during the simulation period. Atrazine and paraquat represent a dissolved and a sediment-attached pesticide, respectively, and the losses show the effects of the management practices on runoff and erosion. Atrazine is transported mainly in water, and the reduced runoff from chisel plowing and terracing (Practices 3 and 4, Table 1) reduced losses by about 60 percent. The slight changes in loss from practices 1 to 2 to 4 reflect the small amount of atrazine transported by sediment. Since paraquat is transported mainly in sediment, losses are generally closely associated with sediment yield. The exception is for practice 5, where the impoundment resulted in the lowest sediment yield (Table 2). Deposition of coarse particles in the impoundment resulted in the highest enrichment ratio and sediment having the highest fraction of fines. The fine sediment is the main carrier of pesticides attached to sediment. Enrichment of fines resulted in more paraquat loss from practice 5, the impoundment system, than from practice 3, the chisel plow system, where sediment yield was greater.

Utility of results. The relative results of applying the CREAMS model may change for the same practices in other land resource areas or other fields in the same land resource area. Application of the model is site specific, and the examples represent a specific topographic and climatic situation. However, these results demonstrate the utility of CREAMS as a tool to evaluate alternative management practices and the complex interactions among the components for the several practices. The results show that a specific management system may not minimize all pollutants (sediment, plant nutrients, and pesticides). Factors other than minimizing pollutants must be considered in selecting a management practice, such as farm machinery requirements and the farmer's economic constraints.

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