UTILIZATION OF THE KINEMATIC RUNOFF AND EROSION MODEL IN PREDICTING THE EFFECTS OF VEGETATION ON HEAVY METAL CONTAINMENT IN SOUTHEAST KANSAS

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ABSTRACT

In southeast Kansas, where mining activities ceased in the middle half of the twentieth century, heavy metals in residue materials have created surface contamination problems. The erosion losses of chat material, a by-product of mining activities, have elevated levels of cadmium, lead, and zinc in nearby farmland to phytotoxic levels for the crops normally planted. Selective vegetation is being examined as a means of controlling the loss of sediment material and containing the further spread of the metal contaminants. The kinematic runoff and erosion model, KINEROS, is examined to investigate the role vegetation plays in controlling erosion from an 800-acre watershed near Galena, Kansas. Results of the model are compared with predictions made by another non-point source model, the agricultural non-point source pollution model, AGNPS.

Key words: *contamination, erosion, metals, modeling, sediment, vegetation, watershed*

INTRODUCTION

Since 1899, when the first water pollution control law was passed in this country, tremendous strides have been made in understanding and controlling those factors leading to point and non-point source pollution. The United States Environmental Protection Agency was given power to regulate point source pollution by the Clean Water Act of 1972, and more recently, non-point pollution by the Water Quality Act of 1987. Section 319 of this act provides federal funds for states to establish and implement non-point source control programs, one of which is phytostabilization. The use of models to predict the effects of various watershed management practices, including the strategic placement of vegetative covers, will lead to the most efficient non-point source pollution control measures.

In southeast Kansas, after the abatement of mining activities in the middle half of the twentieth century, soil and surface water contamination due to zinc, lead, and cadmium was identified as a serious concern. Chat piles, residue material from previous mining, have high concentrations of the metals, and erosion losses and subsequent spreading of the sediment materials by rainstorm events have contaminated farmland downstream.

In a previous study (Green et al., 1997), an 800-acre watershed west of the town of Galena, Kansas, was selected for simulation to examine which management techniques would be predicted to be most effective in controlling sediment loss. The models do not simulate the partitioning of metals between the aqueous and adsorbed phases, however, the majority of the metal contaminants are found adsorbed to the soil matrix. It is assumed that sediment losses therefore predict a reduction in the amount of heavy metals leaving as well. The same watershed was examined for this study, allowing comparisons in predictions made by the agricultural non-point source pollution model, AGNPS, and the kinematic runoff and erosion model, KINEROS. Located in Cherokee County, Kansas, the presence of numerous tailing piles in the watershed allows for an examination of the influence vegetative covers and buffers have on controlling the spread of the metal contaminants. The outline of the watershed can be seen in Figure 1.

The kinematic runoff and erosion model, KINEROS, is an event-based model which predicts runoff volume and peak runoff rates, as well as erosion losses, from a single rainstorm event. The model, developed with the assistance of the United States Department of Agriculture, with recent updates by Woolhiser, Smith, and Goodrich (1990), is physically based and accounts for such processes as infiltration and interception. The watershed under examination is subdivided into cells which represent both planes and channels, in which water and sediment transport are routed. A maximum of 60 cells can exist for any simulation, and this limits the size of the watershed which can be examined without a significant approximation of watershed characteristics. In order to physically describe the watershed, five categories of inputs are required: simulated rainfall information, watershed topography, channel characterization, surface cover, and soil parameters (Osborn et al., 1990).

Eight divisions, or components, exist within the model, those being: rainfall, interception, infiltration, overland flow, open channel flow, erosion, sediment transport, and reservoir routing and sedimentation. Two parameter files are necessary for model execution. One file describes the physical characteristics of the watershed; the second describes the nature of the rainstorm event (Woolhiser et al., 1990).

Rainfall

The precipitation file created for the watershed can account for variations in precipitation levels as one transgresses the watershed by placement of "rain gauges" within specific elements or cells of the simulated region. By weighting these rain gauges differently, different rainfall amounts can be simulated over the watershed. The hyetograph of the storm event is also inputted, with accumulated depth being entered as a function of time.

Interception

The model accounts for interception by vegetation by subtracting the amount from the total precipitation amounts for the rainstorm event simulated. Interception depth is affected by several factors, including wind velocity, vegetation type, and seasonal growth stages. Model developers provide a table within the operations manual giving reported interception depths for 11 different types of vegetative cover.

Infiltration

Rainfall excess, which leads to runoff, is defined as the difference between precipitation amounts and interception and infiltration depths. The rate at which infiltration occurs is not constant, but depends on the rainfall rate and accumulated infiltration amounts, or the antecedent moisture condition of the soil. One of the benefits of vegetation is that the soil water content is reduced by evapotranspiration. The depression in soil water content increases the amount of precipitation that can infiltrate into the root zone of the soil matrix. If the rate of rainfall is the limiting factor, then infiltration rate equals precipitation rates and no ponding will occur. However, if the rate of rainfall exceeds the infiltration rate, then accumulation of water on the soil surface will occur. The modelers developed a four-cycle process for infiltration:

Rain Limited: When the rainfall rate is small, the rate of infiltration is equal to the rate of rainfall, that is:

$$fc = r, \qquad (1)$$

where fc is the rate of soil infiltration (in/hr) and r is the rate of rainfall (in/hr).

Ponding: Ponding occurs when the rate of rainfall exceeds the infiltration rate,

$$fc = f\left(F,\theta\right), \qquad (2)$$

where F is the amount of rain previously incorporated into the soil, and q is the initial water content of the soil, for the specific rainfall event.

Two key factors affecting infiltration, the net capillary drive, G, and saturated hydraulic conductivity, Ks, are related as follows:

$$G = \left(\frac{I}{K_s}\right)\int_{-\infty}^{O} K\left(\psi\right)d\psi. \qquad (3)$$

K is the hydraulic conductivity function and y is the soil matric potential. Plants also have an effect on the hydraulic conductivity, with soils containing vegetation having a largervalue under saturated conditions.

The saturation deficit of the soil, B, is defined as:

$$B = G\phi\left(S_{\max} - S_i\right), \qquad (4)$$

where Smax is the maximum relative saturation for the soil and S_j is the initial relative saturation for the soil, with relative values defined as the soil water content divided by f, the soil porosity. The authors provide tables which give ranges of values of relative and maximum soil saturation based on soil type.

When F>O, the maximum estimated infiltration rate can be estimated from

$$fc = \frac{\left[K_s \exp\left(\frac{F}{B} \right) \right]}{\left[\exp\left(\frac{F}{B} \right) - 1 \right]}. \qquad (5)$$

Initially, the soil infiltration rate follows the rainfall rate; however, when fc estimated from equation (5) is less than r, then equation (5) is utilized to estimate fc. Values for the saturated hydraulic conductivity, net capillary drive, porosity, and maximum saturation are given in terms of soil types. As the amount of infiltration increases, fc decreases until fc = K_s the hydraulic conductivity in saturated soil.

Recession: The kinematic runoff end erosion model accounts for infiltration during recession, where r < fc, by factoring in the "smoothness" of the surface in the parameter RECS, which measures the depth above which the entire surface of the cell is under water. Larger values for RECS correspond to rough surfaces, while smaller values simulate relatively smooth surfaces. When the depth of the runoff decreases below the RECS value, the percentage of the surface experiencing runoff decreases proportionally (Woolhiser et al., 1990).

Rainfall Hiatus: If during the rainstorm event, the precipitation rate decreases below that at which moisture is being incorporated into the soil matrix, as measured by the hydraulic conductivity of the soil (r < Ks), and the surface is no longer covered by water, then the "redistribution" of soil moisture must be accounted for by a larger value for the initial soil moisture content when the precipitation rate again exceeds the infiltration rate. The "redistribution" is as follows:

$$S(r) = S_r + (S_{\max} - S_r)\left(\frac{r}{K_s} \right)^P, \qquad (6)$$

where S(r) is the new soil moisture; S_r is the residual soil saturation at the start of the current rainfall event; r is the rainfall rate; and p is approximately 0.20.

Hortonian Overland Flow

Once the precipitation amount exceeds the interception depth and infiltration capacity of the ground, then overland flow can begin. Although a three-dimensional process, when viewed on the large scale, it can be approximated as one dimensional. The amount of flow is made proportional to the storage per unit area through the kinematic assumption that:

$$Q = \alpha h^m, \qquad (7)$$

where Q is the discharge per unit width; h is the storage depth of water per unit area; and m and α are parameters related to surface conditions

The expression is coupled with the equation of continuity:

$$\frac{dh}{dt} + \frac{dQ}{dx} = q(x,t). \qquad (8)$$

The height of water over a cell is a function of time and position and related to the inflow rate as follows:

$$\frac{dh}{dt} + \frac{\alpha m h^{m-1} dh}{dx} = q(x,t), \tag{9}$$

where t is the temporal coordinate; x is the spatial coordinate; and q is the lateral inflow rate of surface runoff from surrounding planes and channels.

With appropriate boundary conditions, the kinematic wave equations, which are simplifications of the de Saint Venant equations, are solved by a four-point implicit method, the Newton-Raphson technique. The parameters m and α, dependent upon slope and surface roughness, are determined using one of four "resistance laws" in the model. These four laws include the Manning's hydraulic resistance law, a laminar law used with Manning's law, Chezy's law, and the laminar law used with Chezy's law. Resistance parameters for each of the laws are provided in the operations manual. For purposes of this study, Manning's resistance law was employed, as Manning's n is also used in the agricultural non-point source pollution model, AGNPS (Young et al., 1989;AGNPS, 1994).

Open Channel Flow

As with overland flow, the kinematic equation describing channel flow is solved by the four-point Newton-Raphson iteration method. Inputs into channel flow can occur from other channels or overland flow entering the channel from the end or sides. Direct rainfall input into the channel is not accounted for. Utilizing the kinematic assumption, the relationship between the cross-sectional area of the channel and discharge is as follows:

$$Q = \alpha R^{m-1} A, \tag{10}$$

where R is the hydraulic radius of the channel and A is the cross-sectional area of the channel. The cross-sectional area of the channel can be approximated as either circular or trapezoidal. Sufficiently large side slopes for the channels can be selected so that simulation of a rectangular channel is also possible. For the watershed under study, no sewer or piping systems existed to channel water flow, thus all channels were simulated as trapezoidal. Again, parameters dependent upon surface conditions, m and a, were determined using Manning's equation:

$$m = \frac{5}{3} \tag{11}$$

$$\alpha = 1.49 s^{\frac{1}{2}} n^{-1}, \tag{12}$$

where s is slope and n is Manning's roughness coefficient. The appropriate Manning's n value is dependent upon the channel material and shape.

Erosion and Sediment Transport

KINEROS accounts for two distinct types of sediment erosion: erosion caused by raindrop impact and erosion resulting from surface water flow. Erosion caused as a result of surface flow can be upland erosion or channel erosion. Deposition resulting from decreased surface-flow velocities when going through larger water bodies, such as ponds, is accounted for as well.

The model developers report that the following mass balance equation is used to model sediment movement along the watershed:

$$\frac{d\left(AC_s\right)}{dt}+\frac{d\left(QC_s\right)}{dx}-e\left(x,t\right)=q_s\left(x,t\right), \tag{13}$$

where A is the cross section area of flow; C_s is the sediment concentration; e is the rate of erosion in the soil; and q_S is the lateral sediment inflow for the channels.

As stated, erosion is caused by impact and surface flow. The sum is

$$e=g_s+g_h, \tag{14}$$

where g_s is splash erosion;

$$g_s=c_f k\left(h\right)rq, \tag{15}$$

and g_h is hydraulic erosion.

$$g_h=c_g\left(C_{mx}-C_s\right)A. \tag{16}$$

The splash erosion rate, g_s, is a product of a rain splash coefficient; c_f a reduction factor dependent upon water depth, k(h), and rainfall excess, q. In equation 16, c_g is the hydraulic erosion parameter; C_{mx} is the sediment load concentration at the given hydraulic and turbulent conditions; and C_s is the current sediment load concentration.

The erosion due to impact, or splash erosion, is always additive, while the term accounting for hydraulic erosion can add to or decrease erosion, depending upon the rate at which water flows. Splash erosion is not taken into account when examining channel erosion, and if no input occurs at the end of the channel as a result from lateral inflow, then deposition results. Hydraulic erosion is proportional to the difference between the carrying capacity of the stream when at steady state and the current sediment load.

The hydraulic erosion parameter accounts for the "cohesiveness" of the soil matrix. As water velocity increases, so does its carrying capacity. The KINEROS model can utilize six different sediment transport relationships: the empirical "tractive force" and Bagnold relations, the unit stream power relation, the Ackers and White relation, the Yalin relation, and the transport relation of Engelund and Hansen. All relations use slope, velocity, and depth of flow. Some relations are highly dependent upon specific gravity and the mean particle size of the soil. Model developers report particle size limitations in the unit stream power and the Ackers and White relations. The Yalin relation is also questioned in its validity to transport over planar surfaces. The Engelund and Hansen relation is reportedly valid over a range of particle sizes. Comparisons of all six relations were completed for the watershed under study. When routing through a pond or other water body, particle size distribution becomes important, with settling velocities being sensitive to particle size. A normal distribution is assumed for particle sizes in each model element, with the mean and standard deviation for soil particles being parameters to be entered for each.

METHODS

The watershed under examination was previously modeled using the agricultural non-point source pollution model, AGNPS (AGNPS, 1994). To perform a comparison between results of the two models, boundaries of the catchment used in the first simulation are used here. Additionally, while AGNPS subdivides the watershed into square cells of equal size, the kinematic runoff and erosion model allows the user to customize the element size and shape. The cells in KINEROS were designed in order to alternate between barren conditions for the chat material and placement of vegetation buffers and covers within the same regions, as was done for the AGNPS model. However, 60 elements are the maximum permitted by KINEROS, and unlike AGNPS, the element number must also include channels present within the watershed.

Boundaries of the catchment were defined using topographic maps of the Baxter Springs Quadrangle, in Cherokee County, Kansas, provided by the State Geologic Survey. About one quarter of the data entry required for each element can be determined from the survey maps. Such input parameters include both plane and channel slopes. overland flow lengths, and cross-sectional lengths of planar elements. As mentioned, the definition of elements within the watershed was partially based on the simulation of vegetation buffers and covers within the AGNPS model. Thus flow paths from element to element within the KINEROS model were such that vegetation buffers could be simulated in the same manner. Figure 2 shows the watershed and the corresponding division of elements within. Those elements shaded contain chat material.

For this watershed, nine elements are channels and the remaining 39 are overland planes. Of the planar elements, 17 contain chat material. Once the watershed is subdivided, other physical descriptions must be entered, including land use and cover, and soil characteristics. Input parameters which describe the land cover for an element include surface roughness coefficients and vegetative interception depths. Reported values of each are found in the model's documentation and user's manual. Soil characteristics are simulated by entry of the soil particle size distribution, particle density, percent rocks found in the soil, actual and maximum relative soil saturation, porosity, and infiltration rates. Ranges for soil saturation, porosity, and infiltration rates are provided by model developers and are based on soil composition.

In order to gain as accurate values as possible, six samples of the chat material were taken by researchers at experimental sites just north of the watershed being examined. Analysis of the collected chat material found the material to consist of 87% sand, 11% silt, and 2% clay. Density of the chat material was determined to be 3.1 g/cm^3 by weighing the samples and volumetric displacement of water when the samples were submerged. The remaining input parameters for the elements include printout commands and the selection of erosion laws. KINEROS offers the selection of one of six erosional laws. A comparison of all six is performed in a simulation of the watershed in its present state. Figures 3 and 4 show examples of input files required for each element of the watershed.

The influence of vegetation on controlling sediment loss and runoff reduction was examined by simulating both the strategic placement of vegetative buffers and by providing a complete cover over those regions containing chat material. Ongoing research being performed by Pierzynski, et. al., indicates that the addition of proper soil amendments can enable the establishment of a 75% grass cover on previously barren chat soils. Thus, the vegetative buffers were simulated as having an effective cover of 75%. Additionally, simulations were run where those regions containing chat material contained a 25%, 50%, 75%, and complete grass cover. In addition to disrupting and decreasing surface flow, a vegetative cover also hinders erosion caused by raindrop impact. KINEROS relates rainsplash erosion to the universal soil loss equation's soil erodibility factor, the clay content, and exponentially to the mass of vegetation cover per unit area. Figure 5 shows the placement of simulated vegetative additions to the watershed.

As with the agricultural non-point source pollution model, trials examining the benefits of terracing or effective slope reduction were also performed. Those regions containing chat material and having an effective slope exceeding one percent were reduced to one percent. Unlike AGNPS, only the slope, and not the effective slope length, could be changed. Finally, a parameter sensitivity analysis was completed.

In addition to development of the watershed parameter file, a precipitation file for the storm event has to be created. Within the precipitation file, the variation of rainfall rate with respect to both position and time is entered. Spatial variations in precipitation are modeled by specifying the placement of gauges within the watershed and entering a weight factor for each gauge. Temporal variations in rainfall are simulated by entering the accumulated depth of precipitation as a function of time. Total time of the rainfall simulation must be greater than the simulation time specified by the user. Three rainstorm events, with return periods of two years, ten years and fifty years, each with a constant rate and duration of thirty minutes, were simulated using rainfall data provided by the Kansas Department of Transportation for Cherokee County, Kansas.

RESULTS AND DISCUSSION

Variation in rainfall intensity on KINEROS-predicted effectiveness of vegetation in controlling sediment yield was examined by running three different watershed scenarios at three storm levels. The three watershed scenarios include a simulation of the watershed at its present conditions, a simulation when the regions containing chat have a 75% grass cover, and a simulation where vegetative buffers are present. The three precipitation rates included a two-year, 10-year and 50-year storm event. Model predictions are shown in Table 1.

As expected, an increase in storm intensity increased the tons of sediment lost from the watershed. However, the model's predicted influence of vegetation was not as we expected. Simulation for the two-year storm event predicted an eight percent decrease in sediment yield with the presence of a grass cover; however, it also predicted the placement of vegetative buffers would increase the sediment yield by two percent. KINEROS predicted the effectiveness of both the vegetative cover and buffer to increase with storm intensity, with the grass buffer having the greater ability to control sediment loss. Because it is known that the effectiveness of grasses is limited, with bending of the blades and stalks occurring at higher runoff volumes and rates, the model's prediction of increasing effectiveness with storm event stems from an increased contribution of chat material to sediment yield at higher precipitation amounts, and the presence of either the cover or buffer hinders the transport of the chat sediment off site. The greater decrease in sediment yield with the grass buffer as compared to the grass cover could not be explained.

A comparison of the KINEROS predictions for the watershed at present conditions and those made by the agricultural non-point source pollution model, AGNPS, is shown in Table 2. Predictions made by the kinematic runoff and erosion model were, on average, over 600% larger than those made by AGNPS. Predicted runoff rates, in Table 3, were also higher for KINEROS, but runoff volumes were comparable, with KINEROS predicting a higher value with greater storm intensity. The greater sediment yield in Table 2 for KINEROS may be due to the larger peak runoff rate shown in Table 3.

The KINEROS model offers the user the selection of one of six different erosion laws. Two of the laws, the tractive force relation and the Bagnold-Kilinc relation, are reported by the author as "simple conceptual relations" and employ an empirical coefficient, with the local flow velocity being the key hydraulic feature for the tractive force law and the local water depth and hydraulic bed shear being key contributors in the Bagnold equation (Woolhiser et al., 1990). The unit stream power, Ackers and White, Yalin, and Engelund and Hansen relations all use particle characteristics, such as specific gravity and diameter, and water viscosity to predict sediment transport. Both the Ackers-White and unit stream power relations have a lower limit on particle size that can accurately be predicted by the laws. A 0.04 mm limit exists for the Ackers-White erosion law and the unit stream power function has a 0.062 mm limit, as reported by model developers. Thus, those regions containing chat, which has a high sand content, would fall within the validity of these relations, but those uncontaminated planes where the indigenous soil is a silt loam would not. Another law, the Yalin relation, which also depends on particle size and shear velocity, is reported by model developers as predicting a decrease in particle size leads to a reduction in transport capacity at certain diameter-to-flow-depth ratios. Model developers report the last erosion law, the Engelund and

Hansen relation, to be valid over a large range of particle size. Predictions on sediment yields for the watershed under present conditions, or conditions without added vegetation, for a two-year storm event are shown in Table 4.

The Engelund-Hansen relation predicts an erosional loss midway between the values predicted by the two empirical methods, while the other three-dimensionless relations have much higher predicted losses. For this storm event and watershed condition, the agricultural non-point source pollution model predicted a sediment yield of 60 tons.

The introduction and establishment of vegetation affects soil conditions in numerous ways. In order to establish the effect of the presence of a plant cover or buffer, a sensitivity analysis was performed on those parameters whose values are subject to change. Table 5 displays the results of the analysis. The parameters were adjusted to values both 90% and 110% of the nominal values given in Figures 3 and 4.

The infiltration rate (FMIN), net capillary drive (G), porosity (POR), and relative soil saturation (SI) are all dependent upon soil type while the rain splash and hydraulic erosion parameters (CF, CG, CH) are not. Both those regions containing the chat material and those that contained no chat, or were "clean" of any contamination, were examined.

The sensitivity, reported in Table 5, was calculated as

$$\frac{\left(\frac{\Delta s}{s_i}\right)}{\left(\frac{\Delta x}{x_i}\right)}, \quad (17)$$

where Δ_s is the change in model output; s_i is the nominal output; Δ_x is the change in parameter value; and x_i is the nominal parameter value.

For the two-year storm event, altering the various parameter values in those regions which contain the chat material had no effect in the predicted model output for the watershed under examination. Examination of the chat regions, on an element-by-element basis, found that these regions contribute little, if at all, to sediment yield. If vegetation were reestablished on those regions, the relative soil saturation would decrease due to evapotranspiration; the hydraulic conductivity would increase; the growth and decay of roots would produce macropores and change the porosity of the soil; and the resulting cover would reduce the amount of precipitation reaching the earth, as well as providing resistance to raindrop impact and splash erosion. Adjustments of these parameters in the chat region showed no significant effects. Reduction in rainfall amounts by interception was not examined directly because the current rainfall rate was insufficient to produce sediment yield.

An examination of KINEROS output files indicated that six of the 17 elements modeled to contain chat material did not contribute any sediment loss, even at the 50-year storm event. Two of those cells, as well as the "clean" vegetated region containing the native silt loam soil downslope from the chat regions, were used to examine which parameters' values most contributed to sediment production. The nominal condition, or base case run, predicted that sediment losses for the subwatershed were only from the region containing the silt loam soil. As can be seen in Table 6, when the parameter values for the soil in that element were altered as to model them as chat material, the sediment yield dropped to zero for a two-year storm event, and increasing the precipitation rate to that of a 50-year storm event did not produce any sediment loss either. When all three elements were modeled as containing silt loam soil, sediment loss was reported for all. A series of cases were then run in which the parameter values for the chat material were changed, bringing them closer to those values reported for silt loam soil. Each case was built consecutively off the last. Thus for the second case, density of the chat was reduced to one third its value and the diameter was reduced to 25% of its original value.

Even with changes designed to bring the parameter values for the chat material more in line with values reported for the silt loam or "clean" soils, model results were unaffected.

Changes included reducing the saturated hydraulic conductivity to 25% of its original value, reducing the soil density by two thirds, reducing the chat diameter to one fourth its original value, increasing the relative soil saturation and capillary drive by 300%, and doubling the rain splash and hydraulic erosion parameters. Still no sediment loss was reported from either of the former chat elements

Based on the Green-Ampt infiltration model (Viessman and Lewis, 1996), the estimated infiltration rate for the chat material, which has a structure similar to sand, was in excess of 8.8 inches per hour, higher than any of the precipitation rates examined. Experimental studies performed on the chat material collaborate this result with the experimenters (Pierzynski et al.) finding a large amount of simulated rainfall was necessary to achieve any runoff.

CONCLUSIONS

Results from the kinematic runoff and erosion model, KINEROS, were ambiguous. While the predicted sediment loss for varying rainstorm intensities followed expected trends, incorporating the effects of vegetation did not. While placement of grass covers decreased overall yield from the watershed, placement of buffers led to an overall increase in sediment yield for the two-year simulated rainstorm event. For higher intensity storm events, the model predicted the grass buffers to have the greater ability in limiting erosion losses. The predicted erosion loss and runoff rates were higher with KINEROS than the agricultural non-point source pollution model, or AGNPS. However, the runoff volumes were comparable. A sensitivity analysis revealed that altering those parameters which would best simulate the presence of vegetation on chat material had limited effects on the overall sediment yield from the watershed. Further analysis showed that infiltration rates of the chat material are sufficiently large to limit runoff and erosion losses to those cases where contributions from upland elements are present. These findings are supported by experimental work.

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NOMENCLATURE

BW	Channel bottom width, ft
CF	Rain splash parameter
CG	Hydraulic erosion transfer coefficient rate
CH	Rain splash erosion damming parameter, in.
CO-CS	Parameter in either the Kilinc and Richarson erosion relationship or tractive force erosion relationship
D50	Median sediment particle diameter, ft
DIAM	Conduit channel diameter, ft
DINTR	Interception depth. in.
FMIN	Saturated hydraulic conductivity, in/hr
G	Effective net capillary drive, in.
J	Element n~lmher
LAW	Code for erosion law, 1 designates tractive force law
NCASE	Code for channel type, 1 designates trapezoidal channels
NC1	Element number of first channel contributing at upstream boundary
NC2	Element number of second channel contributing at upstream boundary
NL	Element number of plane contributing to left side of channel
NPNT	Pond code, 0 designates a plane or channel
NPRIN	TCode for detailed printout in auxiliary file, I designates do not print
NR	Element number of plane contributing inflow to right side of channel
NRP	Code for printout of rainfalland intermediate runoff rates in the primary output file, 0 designates do not print
NU	Element number of plane contributing to upstream boundary
PAVE	Proportion of area covered with gravel. PAVE = 1 designates a paed
POR	Soil porosity
Rl	Manning's n if Manning's law is used in resistance law
R2	Laminar k used in laminar Manning's and laminar Chezy's laws
RECS	Infiltration recession factor, in.
RHOS	Specific gravity of sediment particles
ROC	Volumetric rock content of soil
S	Slope
SI	Relative soil saturation
SIGMAS	Standard deviation of sediment particle
SMAX	Maximum relative saturation under imbibition
W	Width of plane, ft
XL	Length of plane or channel, ft
ZL	Side slope of left side of trapezoidal channel
ZR	Side slope of right side of trapezoidal channel

Table 1. Effects of grass covers and buffers and rainfall amounts on the overall sediment yield from the watershed under examination.*

Storm Event (years)	Barren (tons)	Grass Cover (tons)	Sediment Yield Percent Reduction	Grass Buffer (tons)	Percent Reduction
2	312.6	288.4	7.7	319.9	-2.3
10	1477.4	866.0	41.4	777.2	47.4
50	3632.0	1356.4	62.7	1203.4	66.9

* The tractive force erosion model.

Table 2. Comparison of predicted runoff rates and volume, and sediment yield for the watershed under present condition.

Rainfall Event	Land Cover	AGNPS Results (tons)	Kineros Results (tons)
2 year	Barren Grass Buffer Grass Cover	60.1 49.2 22.3	312.6 319.9 288.4
10 year	Barren Grass Buffer	199.0 158.4	1477.4 777.2
50 year	Barren Grass Buffer	599.1 461.0	3632.0 1203.4

Table 3: Comparison of predicted runoff rates and volumes from KINEROS and AGNPS for the watershed under present conditions.

Rainstorm Event	Watershed Condition	Variable	AGNPS	KINEROS
2-year	barren	runoff depth	0.13 in.	0.05 in.
	chat regions	peak runoff rate	19.4 cfs.	94.9 cfs.
10-year	barren	runoff depth	0.33 in.	0.38 in.
	chat regions	peak runoff rate	99.4 cfs.	431.4 cfs.
50-year	barren	runoff depth	0.62 in.	0.76 in.
	chat regions	peak runoff rate	258.4 cfs.	810.2 cfs.

Table 4. Predicted sediment yield from various erosion laws for a two-year storm event.

Rainfall Event	Erosion Law	Kineros Results (tons)
2-year	Tractive Force	312.6
	Unit Stream Power	1166.2
	Bagnold/Kilinc	289.5
	Ackers and Whilte	785.7
	Yalin	1111.6
	Engelund and Hansen	298.8

Table 5. Results of sensitivity analysis for the watershed under examination for a two-year storm event.

Parameter	Original Total Sediment (tons/storm)	Adjusted (0.9) Total Sediment (tons/storm)	Sensitivity	Adjusted (1.1) Total Sediment (tons/storm)	Sensitivity
FMIN (clean region)	312.6	354.4	-1.34	303.7	-0.29
FMIN (chat region)	312.6	312.6	0.00	312.6	0.00
G (clean region)	312.6	349.1	-1.17	309.9	-0.09
G (chat region)	312.6	312.6	0.00	312.6	0.00
POR (clean region)	312.6	349.1	-1.17	309.9	-0.09
POR (chat region)	312.6	312.6	0.00	312.6	0.00
SI (clean region)	312.6	308.1	0.14	352.0	1.26
SI (chat region)	312.6	312.6	0.00	312.6	0.00
CF (clean region)	312.6	312.6	0.00	312.6	0.00
CF (chat region)	312.6	312.6	0.0	312..6	0.00
CG (clean region)	312.6	312.6	0.00	312.6	0.00
CG (chat region)	312.6	312.4	0.01	312.9	0.01
CH (clean region)	312.6	312.6	0.00	312.6	0.00
CH (chat region)	312.6	312.6	0.00	312.6	0.00

Table 6. Analysis of parameter values on sediment yield from subwatershed.

Storm Event (years)	Parameter Values for Chat Regions	Sediment Output (lbs)
2	original values	46.6
2	0.25 * Diam	46.6
2	0.25 * Fmin	46.6
2	3 * G	46.6
2	3 * SI	46.6
2	"all silt loam"	$1.4 + 10^6$
2	"all chat"	0.0
50	"all chat"	0.0

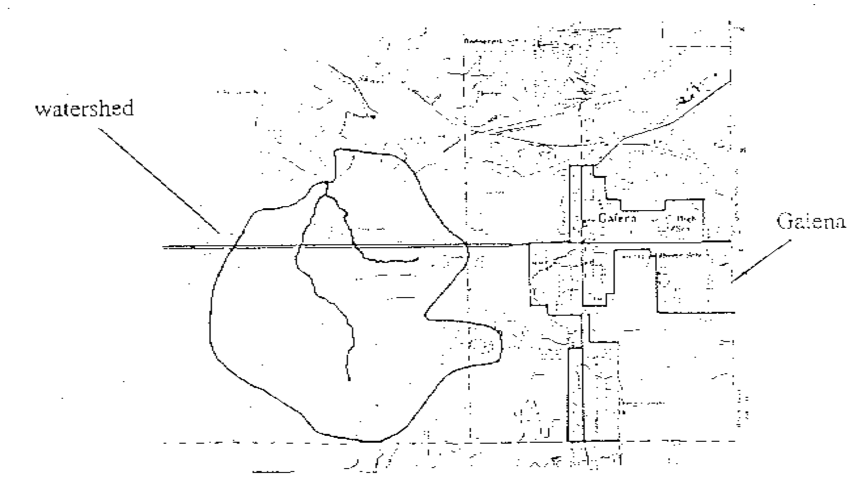

Figure 1. Location of the watershed under study near Galena, Kansas. Taken from a topographic map of the Baxter Springs Quadrangle, Kansas.

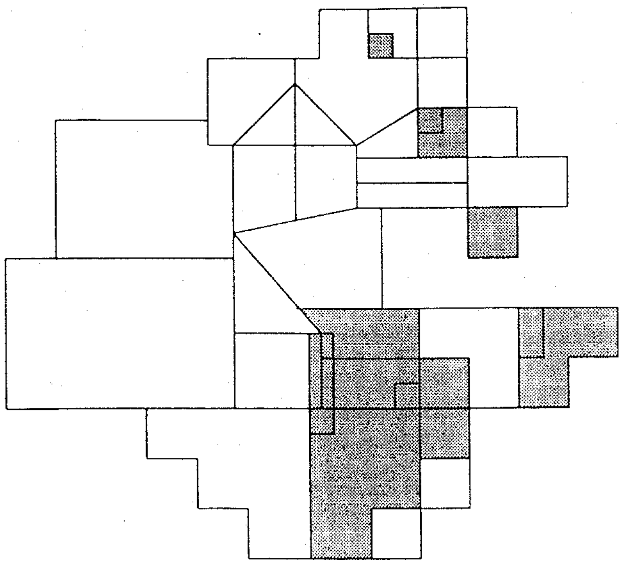

Figure 2. KINEROS simulation of the watershed under study. Regions containing chat material are shaded.

```
*
 J      NU      NR      NL     NC1     NC2   NCASE  NPRINT    NPNT     NRP
25      26       0       0       0       0       0       1       0       0
-------------------------------------------------------------------------------
        XL       W       S      ZR      ZL      BW    DIAM      R1      R2
    1143.0  1143.0    0.03     0.0     0.0     0.0     0.0    0.13     0.0
-------------------------------------------------------------------------------
      FMIN       G     POR      SI    SMAX     ROC    RECS   DINTR
      0.27     8.0     0.5     0.5    0.97    0.05     0.2    0.08
-------------------------------------------------------------------------------
       LAW      CF      CG      CH   CO-CS     D50    RHOS    PAVE  SIGMAS
         1     100   0.011     203   0.001 0.00008     1.5    0.00     0.0
*
```

Figure 3. Input parameter file for a silt-loam or "clean" element in KINEROS.

```
*
 J      NU      NR      NL     NC1     NC2   NCASE  NPRINT    NPNT     NRP
26      27       0       0       0       0       0       1       0       0
-------------------------------------------------------------------------------
        XL       W       S      ZR      ZL      BW    DIAM      R1      R2
     330.0   660.0   0.038     0.0     0.0     0.0     0.0    0.01     0.0
-------------------------------------------------------------------------------
      FMIN       G     POR      SI    SMAX     ROC    RECS   DINTR
       7.3    2.61    0.45     0.5    0.95    0.05     0.2    0.00
-------------------------------------------------------------------------------
       LAW      CF      CG      CH   CO-CS     D50    RHOS    PAVE  SIGMAS
         1     100   0.011     203   0.001  0.0005    3.11    0.00     0.0
*
```

Figure 4. Input parameter file for a "chat" element in KINEROS.

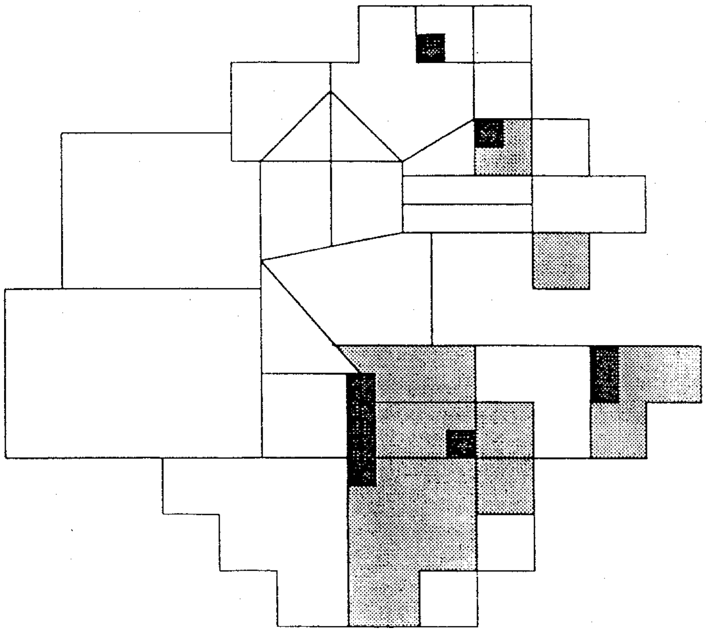

Figure 5. KINEROS simulation with vegetative buffers and covers. Regions containing buffers are shaded. Regions containing covers are shown in black.