IMPACT OF CLIGEN PARAMETERS ON WEPP-PREDICTED AVERAGE ANNUAL SOIL LOSS

C. Baffaut, M. A. Nearing, A. D. Nicks

ABSTRACT. *The combination of the weather generator program CLIGEN and the Water Erosion Prediction Project (WEPP) model provides a way to predict runoff and erosion for individual rainfall events for long periods of simulation. The purposes of this study were to: 1) investigate the required simulation period necessary to obtain stable long-term annual averages of soil erosion for various environmental conditions; 2) investigate the effects of station-to-station variability of CLIGEN input data on the average annual soil loss predictions obtained from WEPP; and 3) develop methods for reducing unreasonable and undesirable levels of such variation while maintaining the integrity of the models in representing regional trends in erosion differences due to climate. The results showed high variations of the average annual soil loss results when the only changes in the input were the climate parameter values used by CLIGEN from one weather station to another, even when the climate was fairly uniform from station to station. A model was proposed to average climate parameters of the station under consideration with the parameters of the surrounding stations. Results obtained using these averaged input values were much more consistent from one station to another for periods longer than 50 years. For shorter periods (30 years), the annual variability of soil loss was larger than the variability induced by climate parameters and averaging these parameters does not improve the results. A comparison of equal soil loss contours obtained after averaging parameters and isoerodent lines from the RUSLE model showed that both reveal similar trends. In mountainous regions this model was not applied because changes in climate of two adjacent stations were sometimes abrupt.* ***Keywords.*** *Soil erosion, Kriging, Climate, WEPP, Model, Simulation, Weather generator, CLIGEN.*

The combination of the weather generator program CLIGEN (Nicks and Lane, 1989) and the Water Erosion Prediction Project (WEPP) models (Lane and Nearing, 1989; Laflen et al., 1991a) provides a way to calculate runoff and soil loss for individual rainfall events for long periods of simulation. These events may be generated by the CLIGEN program and are described by the precipitation amount, the duration, the time to peak, and the ratio of peak intensity to average intensity. These parameters are statistically representative of the historical records. For events that are found by the WEPP model to produce runoff, soil loss is calculated and summed up over a year to obtain the annual and average annual soil loss. The average annual soil loss estimated by WEPP may be compared with values estimated by other procedures such as the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978), or the Revised USLE (RUSLE) (Renard et al., 1991). When the only changes in input are climate parameter values used by CLIGEN, variations in simulation results reflect the impact of weather characteristics on soil erosion. If equal soil loss contours are interpolated between several stations of a region, these contours can display the regional erosion trends due to the climate. One can expect these contours to be similar in shape and direction to the USLE/RUSLE isoerodent lines which are based on rainfall (Wischmeier and Smith, 1978).

The suitability of a predecessor of the CLIGEN model, WXGEN, to provide weather input for soil erosion and crop productivity predictions has been studied (Wallis, 1993). A statistical comparison of 30-year sequences of generated and observed weather indicated that the sequences of weather generated by WXGEN were often unrealistic. Although monthly rainfall amounts were reasonably predicted, mean monthly maximum and minimum temperatures as well as the frequency of rainfall events were significantly different from observed values. The program CLIGEN, however, was tested at 134 weather stations in the United States (Nicks et al., 1990). The conclusions of the study report that "in less than 10% of the cases for rainfall and maximum temperature, only three months or less were significantly different from the (observed) period means for these variables". The feasibility of using CLIGEN to provide weather input to the hydrological model DRAINMOD had also been investigated (Elliot et al., 1992). This model requires hourly rainfall data to simulate the performance of drainage and subirrigation systems and to estimate their effect on water quality and crop yield. By comparing key parameters such as crop yield and annual runoff and rainfall during a 23-year sequence at two different sites in Ohio, using both generated and observed rainfall data, it was found that

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CLIGEN could be reliably used to disaggregate daily observed rainfall data into hourly data. However, the authors recommended exercising caution in using CLIGEN to generate daily rainfall since DRAINMOD outputs were statistically different at the two sites.

The overall goal of this study was to study regional erosion trends due to climate, as predicted by CLIGEN and WEPP, and to investigate the effect of station-to-station variations of CLIGEN input data on the average annual soil loss predictions obtained from WEPP. For analyzing and comparing management practices, station-to-station erosion variations do not necessarily cause problems. However, for state-wide, regional applications, setting acceptable amounts of soil loss for an area requires consistency of the model when changes in a regional climate are gradual. It was therefore necessary to develop a methodology to reduce unreasonable and undesirable variations of average annual soil loss predictions that would preserve the integrity of the model in representing regional trends in erosion differences due to climate. Also, the comparison of the average annual soil loss predictions from station to station required the definition of a minimum simulation period in order to remove climatic variability and to obtain stable long-term averages at each station. The calculation of weather characteristics as well as many of the CLIGEN testing studies are often based on 30 years (Wallis, 1993; Richardson, 1985) because 30-year-long series of daily values of the main weather parameters (precipitation and temperatures) are considered to be statistically representative of the general populations. Our study showed that 30 years are not enough to obtain stable WEPP predictions of the average annual soil loss.

The objectives of the study were to:

- Investigate the minimum simulation period required to obtain stable predictions of the average annual soil loss with WEPP.
- Investigate the effect of station-to-station variability of CLIGEN input parameters on the average annual soil loss WEPP predictions.
- Develop a procedure to reduce unreasonable variations of average annual soil loss predictions from WEPP due to climate.

After determining the required simulation period to ensure a stable average annual soil loss value for all stations, CLIGEN and WEPP were used to predict average annual soil loss and soil loss trends over several states. New soil loss values were then predicted after CLIGEN input parameters were spatially averaged to reduce station-to-station variations of soil loss and to obtain erosion trends that were consistent with the generally accepted trends of erosion potential from climate effect.

MODEL DESCRIPTIONS

WEPP MODEL

The WEPP model is a distributed parameter, continuous simulation, erosion prediction model. Soil loss and soil deposition predictions are calculated based on fundamental hydrological and erosion mechanics processes. Input parameters include daily rainfall amount, duration and intensity of rain, maximum and minimum daily temperature, average daily wind velocity and direction, soil textural characteristics and erodibility parameters, plant growth and residue decomposition parameters, as well as topographic parameters, and a description of the management practices. Additional inputs include irrigation data when necessary. Important parameters for erosion prediction such as roughness, plant growth, soil moisture content, and canopy cover characteristics are updated on a daily basis.

CLIGEN WEATHER GENERATOR

The program CLIGEN is used to generate continuous simulation climate files for use by WEPP. Its input files include a station file (list of all U.S. stations available to run with the program) and state files that contain the weather statistical data for the stations in each state. Weather data statistics for over 1,400 stations within the United States are available to run with CLIGEN. For each station 14 parameters describe the climate conditions, including: the monthly mean, standard deviation and skewness of the precipitation amount per event, the monthly probabilities of a wet day following a wet day and of a wet day following a dry day, the monthly mean and standard deviation of maximum and minimum temperature, the monthly mean and standard deviation of the solar radiation, the monthly mean of the maximum half hour rainfall intensity, the monthly mean of the dew point temperature, and the statistical distribution of the time to peak rainfall intensity. Additional parameters in the CLIGEN input files statistically describe the wind pattern at the station on a monthly basis.

From this file of statistical data, CLIGEN generates, for as many simulation years as desired, the daily rainfall amount and duration, its time to peak as a ratio to duration and its peak intensity as a ratio to average intensity. It also generates minimum and maximum daily temperature and dew point as well as radiation, wind direction, and wind velocity.

The method used to generate the number and distribution of rainfall events uses a two-state Markov chain. A random number generator associated to the probabilities of a wet day following a dry day and dry day following a dry day determines stochastically if precipitation occurs on any given day. If precipitation occurs, the rainfall amount and duration are calculated based respectively on a skewed normal distribution and exponential distribution which are created using input parameters. Peak intensity and time to peak are then calculated in function of rainfall amount and duration.

METHODS

GENERAL PROCEDURE

The effect of climate on average annual rainfall, runoff, and soil loss obtained for Indiana, Alabama, Kansas, Colorado, Washington, and Virginia were predicted. Minimum simulation periods required to obtain a stable average soil loss value were first calculated for each station. Trends with management practices, soil characteristics, and altitude were then analyzed. Finally simulation results obtained when the proposed methodology was used to reduce variations of average annual soil loss predictions were compared with previous results. Equal soil loss contours were compared with isoerodent R-factors lines developed for the RUSLE equation (Renard et al., 1991) in order to compare trends of the erosivity of the climate predicted by the two technologies.

For every available station in the state, 100- or 200-year simulations were performed with unmodified climate parameters and average soil losses were calculated. In every case, a 9% slope field on a 22 × 20 m wide area was used, which corresponds to the standard USLE slope steepness and length conditions. The management scenario was clean-tilled fallow conditions except for Indiana, Alabama, and Kansas where results were also obtained for a conventionally tilled corn cropping system. Soil types depended on the state. In Indiana, Alabama, and Kansas a Miami soil was used. In Colorado results were obtained for a Miami soil and a Woodward soil. In Washington state a Nansene soil and a Palouse soil were used. In Virginia a Frederick soil and an Opequon soil were used. The data for the soil input files were obtained from the WEPP erodibility studies (Laflen et al., 1991b; Elliot et al., 1989).

Shortest simulation periods to reach stability in the average annual soil loss value were determined for each station. The average annual soil loss was considered to be stable when its value was within 10% of the 200-year average soil loss and remained within that interval for any subsequent year. We considered the 200-year soil loss prediction to represent a stable long-term average of erosion. The value of 10% corresponds to the acceptable computational accuracy of the model given in the WEPP *User Requirements* (Foster and Lane, 1987).

Equal soil loss contours were interpolated between these stations using a kriging technique with a linear variogram, no drift and no nugget effect (Isaak and Srivastava, 1989). Although other contouring procedures were investigated, the kriging procedure gave the smoothest contours. They were then visually compared to the RUSLE R-factor lines. R is the erosivity index of the RUSLE equation and describes the effect of climate factors on erosion (Wischmeier and Smith, 1978, Renard et al., 1994). The R-factor comparisons were presented for trend analysis purposes. The intent is not to imply necessarily that the R-factor lines represent infallible trends in erosivity. R-factor variations should show the generally accepted trends of erosion potential from climate effects and are therefore expected to be similar to average annual soil loss variations with climate parameters when all other WEPP parameters remain constant.

Spatial Averaging Method for CLIGEN Input Parameters

A technique was developed to perform spatial averaging of the CLIGEN input parameters in order to establish more consistent trends in the soil loss estimates from WEPP. This technique was developed to reduce the abrupt changes in soil loss predictions from nearby stations for cases where regional trends in climate were gradual. The method involves using weighted averages of specific input CLIGEN parameters between their value at the station and their value at surrounding stations.

The weather generator CLIGEN uses 78 input parameters to calculate daily rainfall, snow, and wind speed and direction. Among these input parameters, 14 describe the rainfall pattern and the general weather characteristics (temperature, radiation, etc.) statistically at the station for each month, the remainder describe the wind pattern. Sensitivity analyses were performed to determine which CLIGEN parameters affected significantly the average annual soil loss predictions. For every station of Indiana, climate files were built with one CLIGEN input parameter being averaged between all stations. Average annual soil loss values were then predicted with WEPP and compared to the soil loss values obtained with initial CLIGEN parameters. These analyses showed that only the following five significantly influence the estimated average annual soil loss: 1) mean precipitation per event; 2) standard deviation of the precipitation per event; 3) skewness of the precipitation per event; 4) probability of a wet day following a wet day; and 5) probability of a wet day following a dry day. The half hour largest intensity and the statistical distribution of the time to peak were not found significant for average annual soil loss calculation purposes.

The technique involves calculating a weighted average of the five input parameters having an influence on predicted soil loss between their value at the station and their value at surrounding stations. A station is considered for the weighted average if there is no more than one degree difference of latitude and/or longitude (to an accuracy of 1) between the main station and this station, including stations in neighboring states. The formula used to weight the value of a parameter at a station with the values of this parameter at surrounding stations is the following:

$$x = (1 - \beta)\, x_0 + \beta(\Sigma\lambda_i x_i) / (\Sigma\lambda_i) \qquad (1)$$

where

x = average value of the parameter

x_0 = original value of the parameter at the station under consideration

x_i = original value of the parameter at the station in quadrant i (there are eight quadrants around a station)

λ_i = weight equal to the inverse of the distance between the main station and station in quadrant i

β = factor that is a function of the number of surrounding stations

If there are no stations within the quadrant i, then $\lambda_i = 0$. If there are several stations in quadrant i, the parameter value x_i is the average of the parameter values for each station in this quadrant. The distance used to calculate the weight is the distance between the main station and the centroid of all stations in this quadrant.

The calculation of β is as follows: $\beta = 0.5\ \Sigma n_i / 8$ with $n_i = 1$ if there is one station or more in quadrant i. Otherwise, $n_i = 0$. If there are no stations around then $\beta = 0$ and the parameter value is equal to the value at the main station. If there are stations in the eight quadrants around, the weight given to the parameter values at the main station is 0.5.

New climate files were built using the averaged CLIGEN parameters and WEPP simulation runs of 200 years were performed for all stations. With new average annual soil loss values for every station of the state, a set of equal soil loss contours again generated and compared to were the isoerodent R-factor lines.

RESULTS AND DISCUSSION

MINIMUM SIMULATION PERIOD

For most stations, 60 years or more were required as the minimum period until average annual soil loss stabilizes while for many of them 50 years were enough, especially when there was large runoff and soil loss (tables 1 through 4).

Table 1 shows the results obtained in Indiana. As the fallow conditions created more runoff and soil loss than corn conditions, the minimum periods were shorter, except for the station of Waterloo. There was no change for the stations of Hobart and Hartford City.

In Colorado, the western stations had very little runoff and soil loss, either because the precipitation amounts were very small or because the runoff originated mostly from snow melt and did not create erosion. The corresponding minimum periods were all 140 years or more. For some of these stations (Del Norte), a 200-year simulation was not enough to reach stability. However, the meaning of the average annual soil loss is questionable when less than one event per year creates erosion. A different parameter may better represent erosion characteristics, for example the average event soil loss.

Annual runoff and soil loss predictions were larger for eastern Colorado stations and simultaneously minimum simulation periods dropped below 140 years. For most stations, it was less than 100 years (table 2). Runoff predictions were smaller with a Woodward soil than with a Miami soil and average annual soil loss predictions were all higher. Minimum simulation periods were generally lower, but many of them were similar.

For the eastern portion of Washington state, the minimum simulation periods approached 200 years because the weather was very dry and only a few events created erosion. Although the soil loss was high for some events, the average annual soil loss value were very low and appeared inadequate to quantify erosion in this situation. Introducing irrigation would have given a more realistic representation of the situation in this area, but it would have introduced another factor in the study that would not permit the comparison of soil loss contours and R-factor lines. Much of the erosion might also be caused by snowmelt. However, the snowmelt erosion capabilities of WEPP have not been thoroughly tested and erosion may be underpredicted. In the west, runoff predictions were larger with a Palouse soil than with a Nansene soil but soil loss values were lower. Minimum simulation periods were shorter or similar.

Table 1. Minimum simulation periods in Indiana for different management conditions

		Corn Conditions			Fallow Conditions		
Station	Avg. Annual Rain (mm)	Avg. Annual Runoff (mm)	Avg. Soil Loss (kg/m²)	Min. Period (yrs.)	Avg. Annual Runoff (mm)	Avg. Soil Loss (kg/m²)	Min. (yrs.)
Waterloo	890	170	2.00	30	185	4.86	60
Hobart	900	165	2.12	30	180	7.09	30
Plymouth	925	175	2.85	120	185	6.68	30
Fort Wayne	920	185	2.04	70	190	4.91	50
Hartford City	905	165	1.57	40	185	5.51	40
West Lafayette	955	195	2.84	60	215	6.83	30
Delphi	945	165	2.70	60	185	6.91	40
Indianapolis	1025	210	2.75	60	215	6.63	40
Greensburg	1070	185	2.75	100	180	6.76	60
Salem	1130	210	4.00	100	210	8.46	40
Terre Haute	940	160	2.68	60	180	7.01	40
Washington	1115	205	2.89	80	200	8.59	20

Table 2. Minimum simulation periods in Eastern Colorado for different soil types*

		Miami Soil			Woodward Soil		
Station	Avg. Annual Rain (mm)	Avg. Annual Runoff (mm)	Avg. Soil Loss (kg/m²)	Min. Period (yrs.)	Avg. Annual Runoff (mm)	Avg. Soil Loss (kg/m²)	Min. (yrs.)
Fort Collins	365	70	2.0	80	30	3.4	40
Greeley	370	60	1.5	80	20	2.2	100
Parker	340	25	1.6	70	10	2.7	70
Canon City	300	15	0.7	90	7	1.1	70
Holyoke	460	85	2.6	80	35	4.8	60
Akron	420	155	2.6	80	55	4.4	40
Limon	320	20	1.4	110	10	2.1	90
Stratton	390	40	2.1	90	20	3.7	30
Walsenburg	390	25	1.4	110	15	2.7	120
Tacony	270	15	0.9	90	6	1.2	110
Timpas	410	30	1.4	120	20	2.9	110
La Junta	290	20	1.3	130	8	1.7	120
Las Animas	320	20	1.3	110	10	2.4	110
Holly	385	45	3.2	60	25	5.5	60
Springfield	385	30	2.3	90	20	3.8	90

* Stations in western Colorado were not included in this table because the average annual soil loss and the minimum simulation period have little significance since so little runoff was produced. Runoff varied between 2 and 70 mm for a Miami soil and 0 and 15 mm for a Woodward soil.

For Virginia (table 4), runoff predictions with an Opequon soil (250 mm in average) were larger than with a Frederick soil (150 mm in average), but soil loss predictions were lower (9 and 4 kg/m^2 in average for an Opequon and Frederick soil, respectively). Lower soil loss values can be explained by a higher critical shear stress, and smaller erodibility values for the Opequon soil. Minimum simulation periods were not very much affected. For most stations, it remained the same or within 10 years, otherwise it was shorter (Winchester and Mathews).

Table 3. Minimum simulation periods in western Washington for different soil types*

		Nansene Soil			Palouse Soil		
Station	Avg. Annual Rain (mm)	Avg. Annual Runoff (mm)	Avg. Soil Loss (kg/m²)	Min. Period (yrs.)	Avg. Annual Runoff (mm)	Avg. Soil Loss (kg/m²)	Min. (yrs.)
Tatoosh Island	1940	330	18	20	680	18	20
Sappho	1880	500	30	50	775	23	30
Long Beach	2010	375	23	30	740	21	5
Clearwater	2910	860	56	20	1385	45	5
Aberdeen	3330	1175	72	10	1760	56	5
Grays River hatch	2780	815	50	15	1315	40	5
Port Angeles	630	30	1.8	140	80	2.3	60
Anacortes	650	15	1.0	130	55	1.4	40
Bremerton	1290	185	10	30	390	11	30
Olympia	1280	150	9	30	340	9	30
Concrete	1710	240	13	20	540	14	10
Cedar Lake	2620	615	32	10	1100	31	5
Packwood	1320	225	12	20	420	11	20

* Stations in eastern Washington were not included in this table because the average annual soil loss and the minimum simulation period have little significance since so little runoff was produced. Runoff varied between 0 and 25 mm for a Nansene soil and 0 and 70 mm for a Palouse soil.

Table 4. Minimum simulation periods in Virginia for different soil types

		Frederick Soil			Opequon Soil		
Station	Avg. Annual Rain (mm)	Avg. Annual Runoff (mm)	Avg. Soil Loss (kg/m^2)	Min. Period (yrs.)	Avg. Annual Runoff (mm)	Avg. Soil Loss (kg/m^2)	Min. (yrs.)
Pennington	1240	190	8.7	20	310	3.9	20
Wise	1145	140	7.4	30	240	3.4	20
Burkes Garden	1100	130	6.0	30	230	2.9	30
Blacksburg	990	115	5.5	30	200	2.6	30
Monterey	955	110	6.1	40	190	2.8	30
Winchester	955	125	7.9	60	210	3.5	10
Big Meadows	1235	275	15	40	390	6.2	40
Manassas	805	100	6.5	20	170	3.0	20
Buchanan	1055	145	9.5	70	245	4.1	70
Columbia	1015	145	8.9	40	240	3.9	40
Richmond	1095	175	12	40	285	5.2	40
Mathews	1050	185	13	40	290	5.4	5
Painter	1060	175	11	40	285	4.7	40

In these four states, shorter periods were obtained when either runoff amount was larger or soil loss values were higher. However, these results are not extensive enough to indicate a clear trend between runoff amount, soil loss values, and length of the minimum simulation period required to get a stable average annual soil loss value. They merely show that there is an intricate relationship between that period and WEPP input parameters, i.e., climate, soil, and management parameters.

These results indicate also that to obtain stable WEPP predictions of the average annual soil loss, 30 years are not enough. In most cases, the minimum simulation period varied between 50 and 100 years. It may be more when significant erosion does not happen every year, a typical situation for dry climates. Although the main driving force for erosion is precipitation, it interacts with the state of the system that is characterized by soil characteristics and management conditions. This interaction results in an increase of the required minimum period to obtain values that are statistically representative of the general population.

STATION-TO-STATION SOIL LOSS VARIABILITY

Equal soil loss contours obtained by kriging, in the case of unmodified CLIGEN parameters, are presented for each state (figs. 1 through 7) and compared to isoerodent lines.

Contours obtained in Indiana for fallow conditions are shown in figure 1. Although soil loss values predicted for a corn cropping system were lower, contours were similar. They were winding and in the northern part of Indiana almost perpendicular to the isoerodent lines. Local variations of soil loss were predicted between neighboring stations. Hobart and Plymouth had high predicted soil losses compared to Fort Wayne although annual rainfall and runoff were comparable. Soil losses in West Lafayette and Delphi were high compared to Hartford City. Note that Delphi and Hartford City had similar amounts of annual runoff (table 1). These differences in soil loss values could not be explained by significant differences in climate. On the other hand, it could be that small variations of monthly values of CLIGEN input parameters cause larger variations is soil loss values because of their interaction with the variables that describe the system (condition of the soil, state of the vegetation, etc.).

In the northern part of Alabama (fig. 2), each station seemed to be isolated; kriging did not allow us to uncover any trend and contours were not in agreement with the R-factor lines. Towards the south, rainfall, runoff, and R-values increased and average predicted soil losses increased even more rapidly. Contour lines and isoerodent lines showed similar trends.

In Kansas (fig. 3), WEPP simulated soil loss contours generally followed the trend given by the R-factor lines. Within this trend some stations had a particular behavior—Pratt with a low soil loss although rainfall and runoff were similar to the values at neighboring stations and Wichita with small rainfall and runoff and low soil loss compared to the values in the nearby stations of Eureka and Howard. It may be that conditions at these stations were very local (Wichita is located in the Arkansas valley) and not representative of the rest of the state. Local conditions have an impact on weather parameters such as temperature, which influence processes such as plant growth or residue decomposition and consequently affect runoff and soil loss values. In the western part of Kansas, a cluster of stations had lower soil loss values that created contours around them instead of following the general direction.

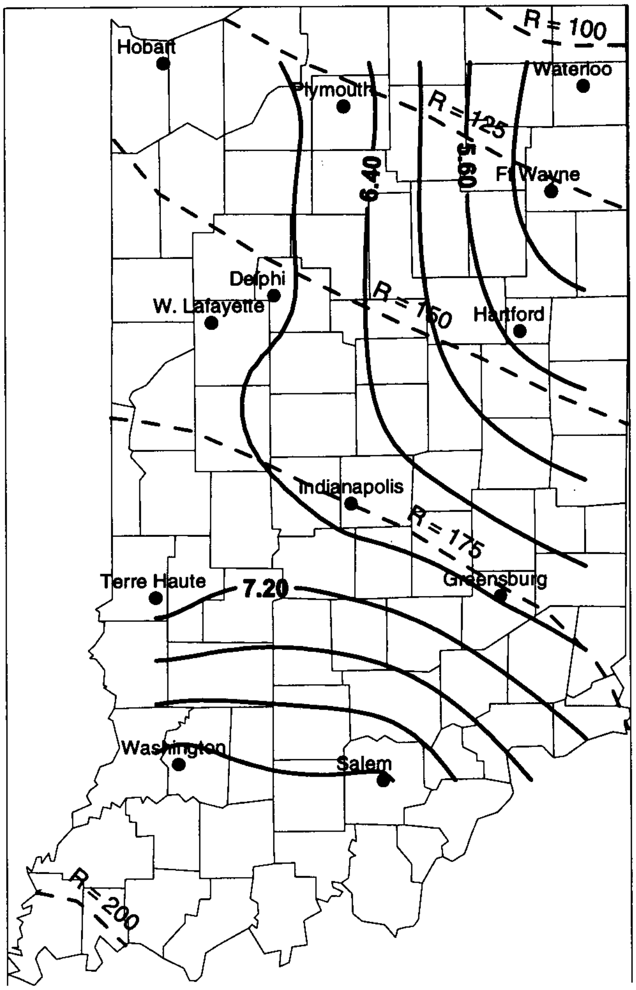

Figure 1–Comparison of soil loss contours (kg/m^2) obtained for fallow conditions in Indiana with RUSLE isoerodent lines (dash lines).

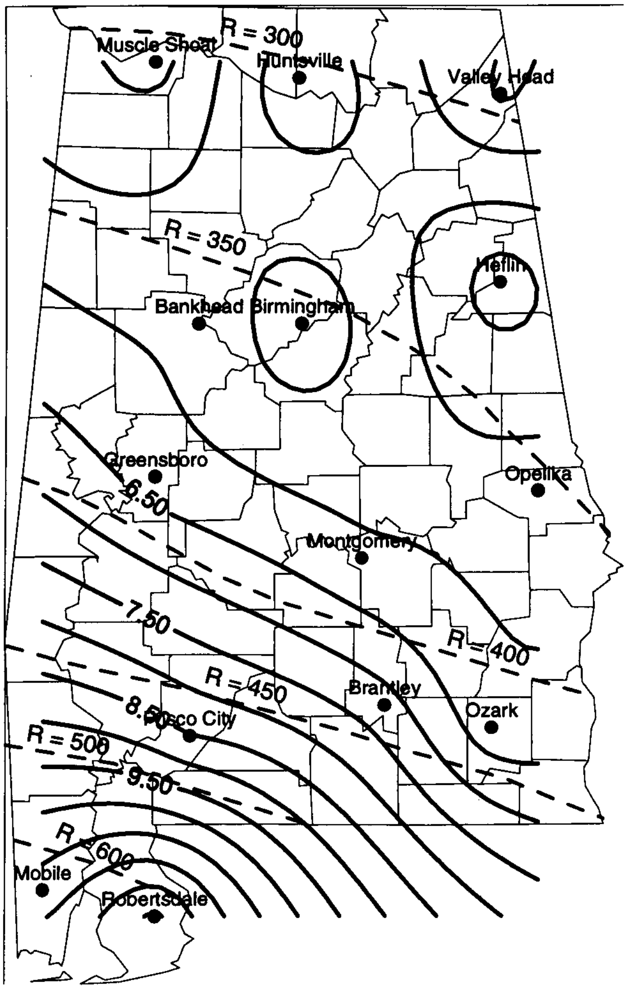

Figure 2–Comparison of soil loss contours in Alabama (kg/m^2) with RUSLE isoerodent lines (dash lines).

In Colorado (fig. 4), only the eastern part of the state is shown because of low values of the average annual soil loss that may not be representative of existing erosion potential. Contours obtained with a Miami soil or a Woodward soil were similar and only the latter are shown. The equal soil loss contours followed the largest patterns of the isoerodent lines. Because, there was more information available to trace isoerodent lines (Istok et al., 1986; Istok, 1989), those were determined with extensive details while the equal soil loss contours were determined only with data from the stations indicated on this figure. This can explain why only the largest patterns were reproduced.

In Washington state (fig. 5), contours in the eastern part of the state were not traced because average annual soil losses there were close to zero and may not reflect the erosion potential. While in the west equal soil loss contours were in agreement with R-factor lines, equal soil loss contours in the center of the state were practically perpendicular to isoerodent lines. This result could indicate difficulties for WEPP to simulate erosion from snow-melt. In addition, more stations are necessary in this part of the state to reflect the impact of elevation and to trace significant contours.

In Virginia, soil loss contours obtained for a Frederick soil were characterized by the high value of soil loss at the Big Meadows station (fig. 6). Similar results were obtained when using Opequon soil. We think that this value was due either to very local conditions of the weather station that should not be taken into account within a regional analysis, or to an error in the CLIGEN input parameters. When the station of Big Meadows was eliminated, soil loss contours were in agreement with the isoerodent lines (fig. 7). In the western part of Virginia (Appalachian mountains), the contours and the isoerodent lines included elevation factors. In the eastern part of the state, erosion increased greatly, which was similar to R-factors.

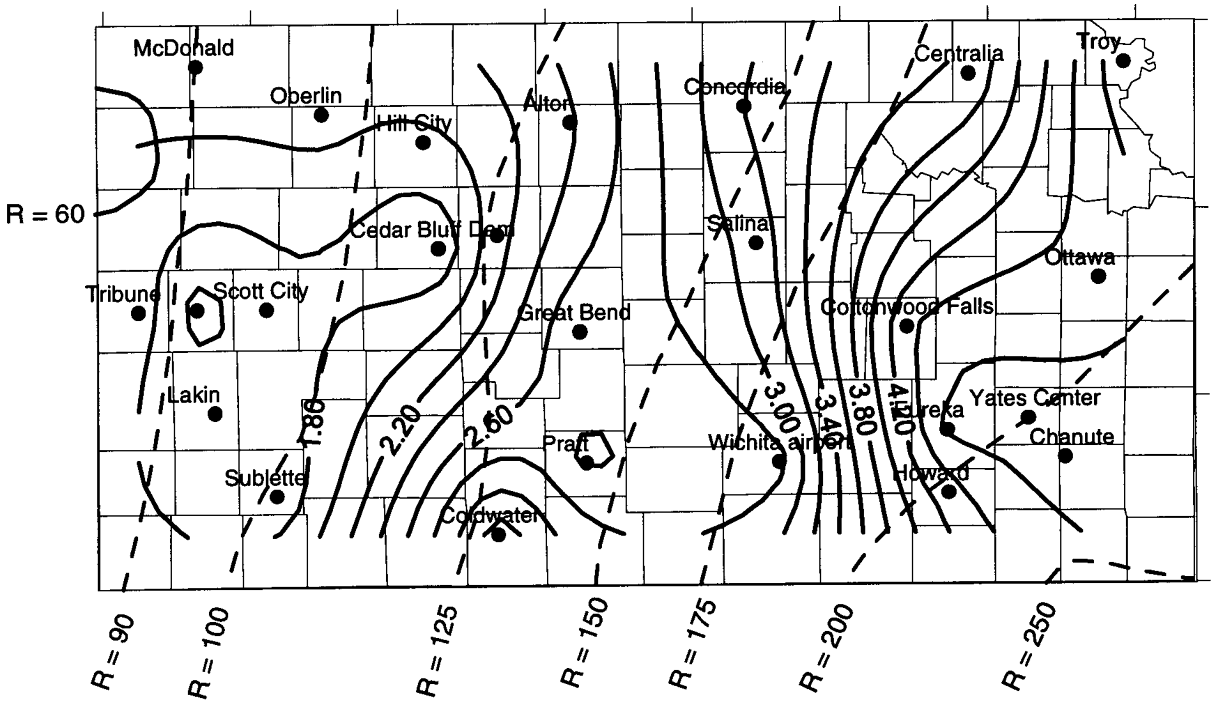

Figure 3–Comparison of soil loss contours in Kansas (kg/m^2) with RUSLE isoerodent lines (dash lines).

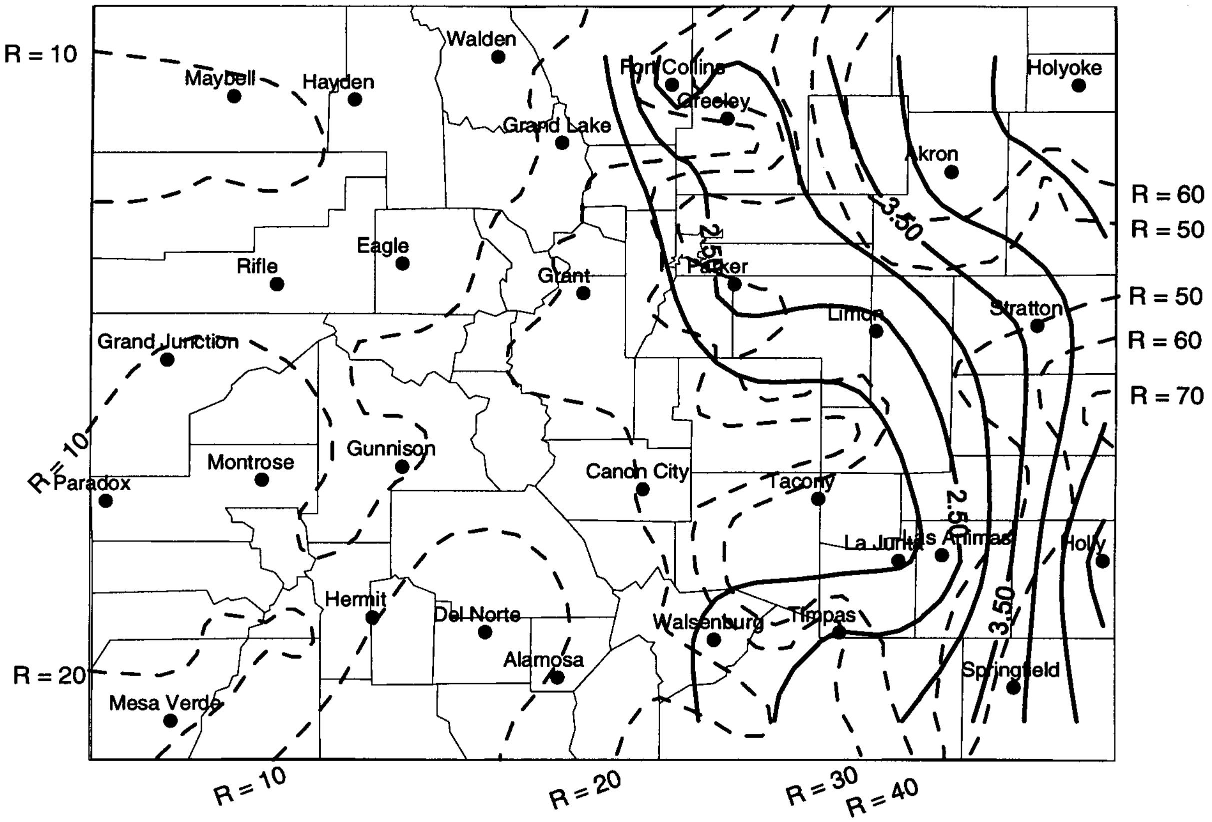

Figure 4–Comparison of soil loss contours (kg/m^2) obtained for a Woodward soil in eastern Colorado with RUSLE isoerodent lines (dash lines).

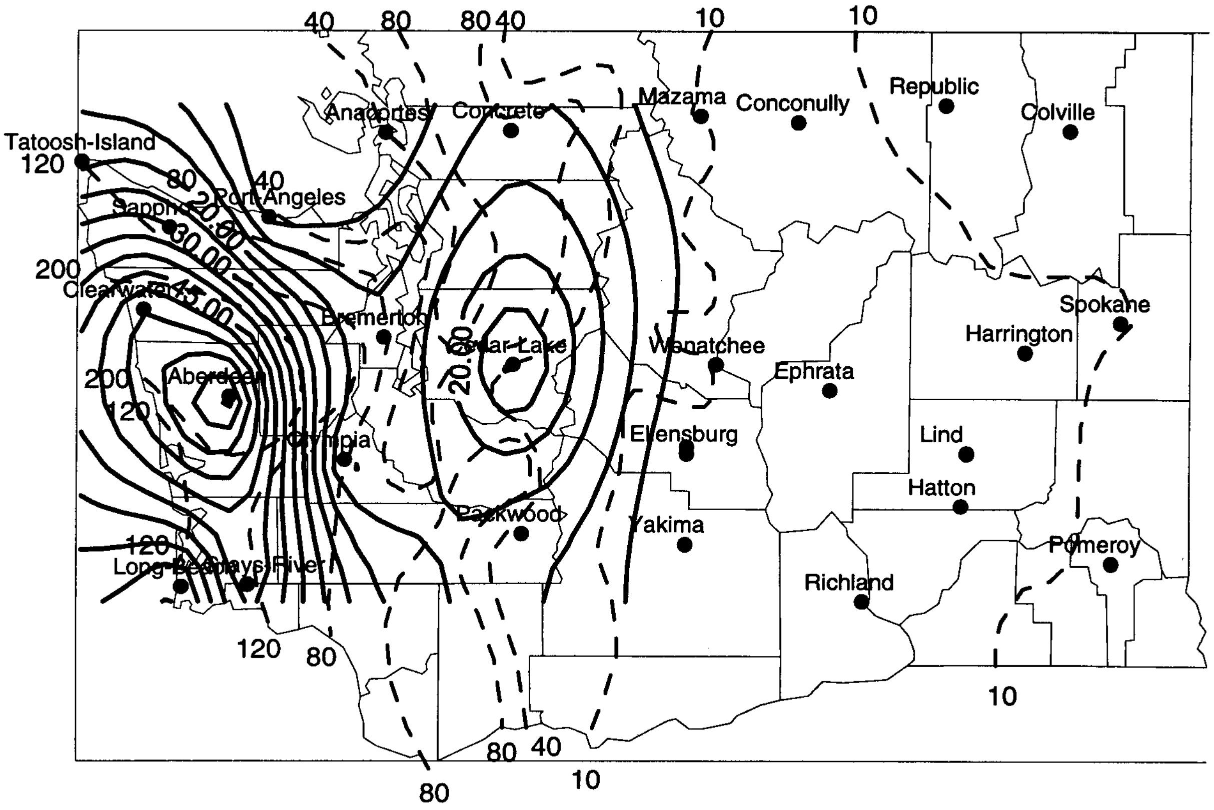

Figure 5–Comparison of soil loss contours (kg/m^2) obtained for a Nansene soil in western Washington with RUSLE isoerodent lines (dash lines).

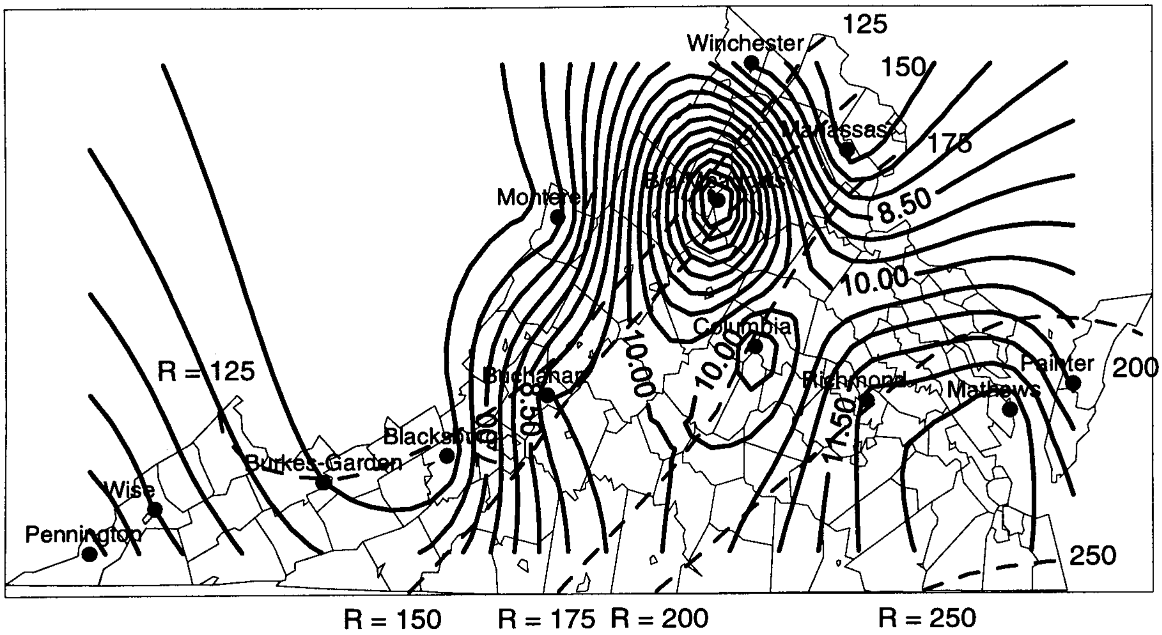

Figure 6–Comparison of soil loss contours (kg/m²) obtained for a Frederick soil in Virginia with RUSLE isoerodent lines (dash lines).

PARAMETER SMOOTHING

Spatial averaging of the CLIGEN input parameters were performed for the states of Indiana, Alabama, Kansas, and Virginia. For these states, climate changes were gradual and were not affected by factors such as high elevation gradients. New equal soil loss contours were determined and compared to R-factors lines (figs. 8 to 12).

In Indiana (fig. 8), results were generally smoothed and more compatible with variations of R-factors values, following a similar trend from north to south. The relative difference between Fort Wayne and Plymouth was more than 30% before parameter smoothing and 15% after parameter smoothing. The improvement was similar for both a corn cropping system and clean-tilled fallow conditions.

In Alabama (fig. 9), results were improved. The contour islands in the northern part of the state disappeared. Although Huntsville was still isolated from Muscle Shoals and Valley Head, the relative differences in soil loss between Huntsville and the two neighboring stations were 30% before parameter smoothing and 10% after parameter smoothing. In the south, contours were fairly similar to contours obtained previously.

In Kansas (fig. 10), results were also improved. Although the soil loss in Wichita was still lower, it became compatible with values at nearby stations. The soil loss

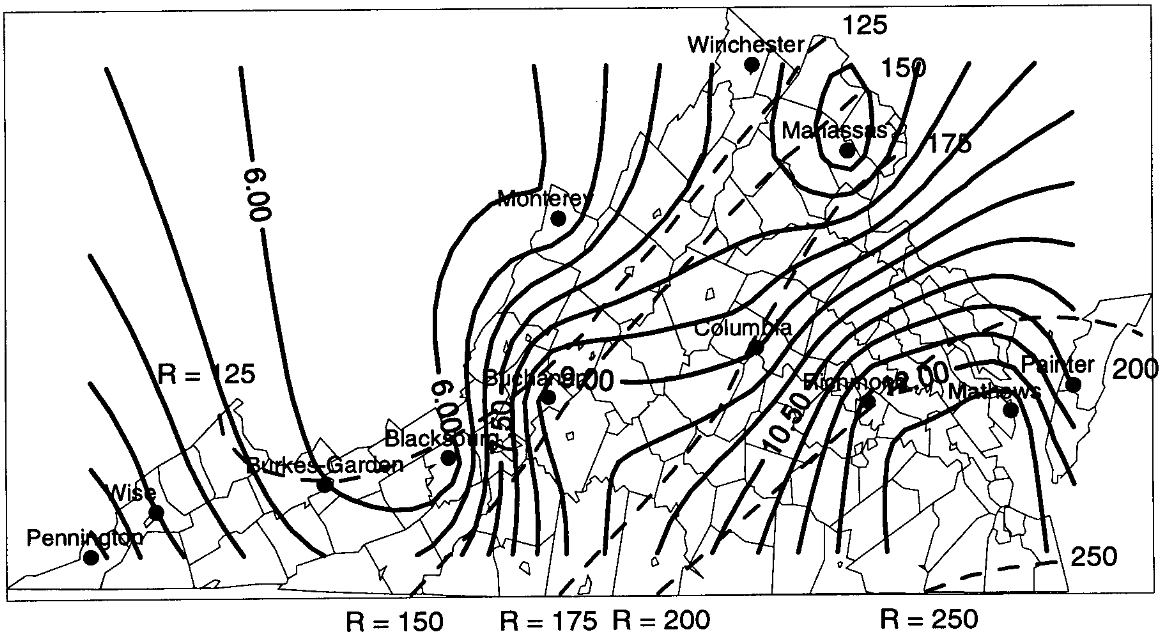

Figure 7–Comparison of soil loss contours in Virginia (kg/m²) with RUSLE isoerodent lines (dash lines) when the Big Meadows station was eliminated.

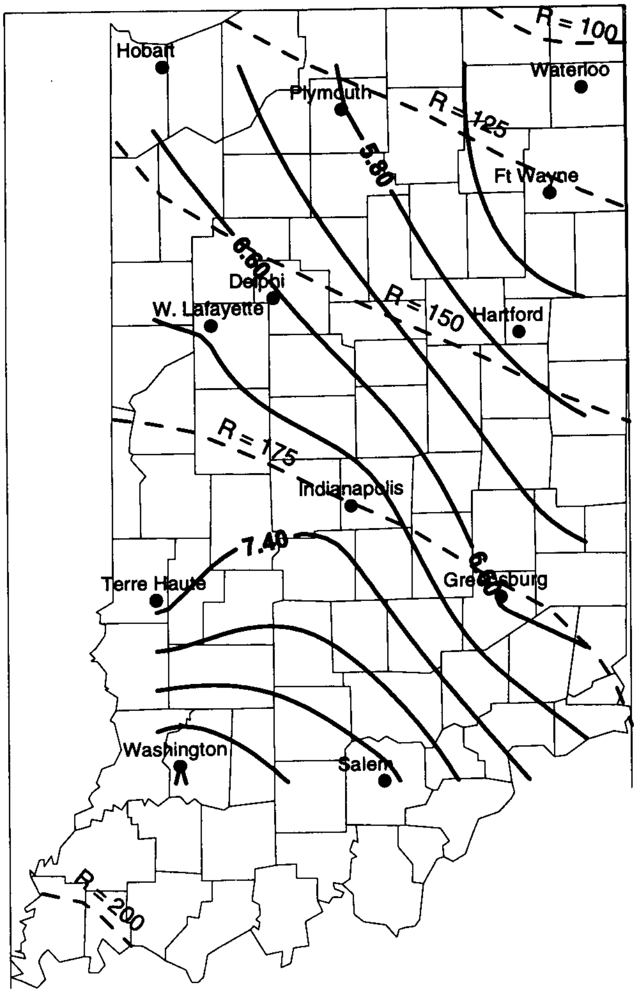

Figure 8–Comparison of soil loss contours in Indiana (kg/m^2) with RUSLE isoerodent lines (dash lines) after parameter smoothing.

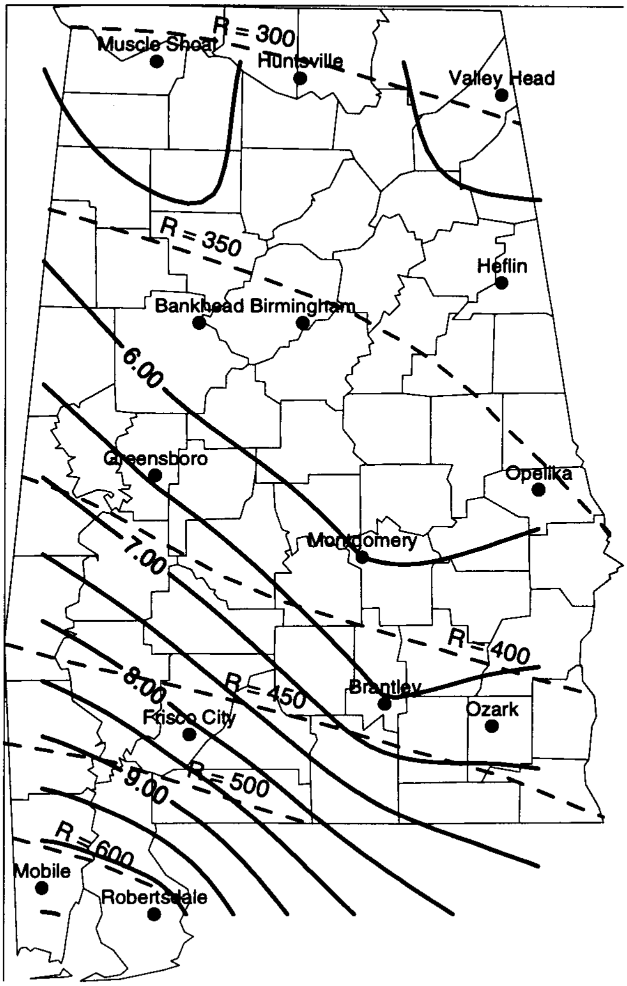

Figure 9–Comparison of soil loss contours in Alabama (kg/m^2) with RUSLE isoerodent lines (dash lines) after parameter smoothing.

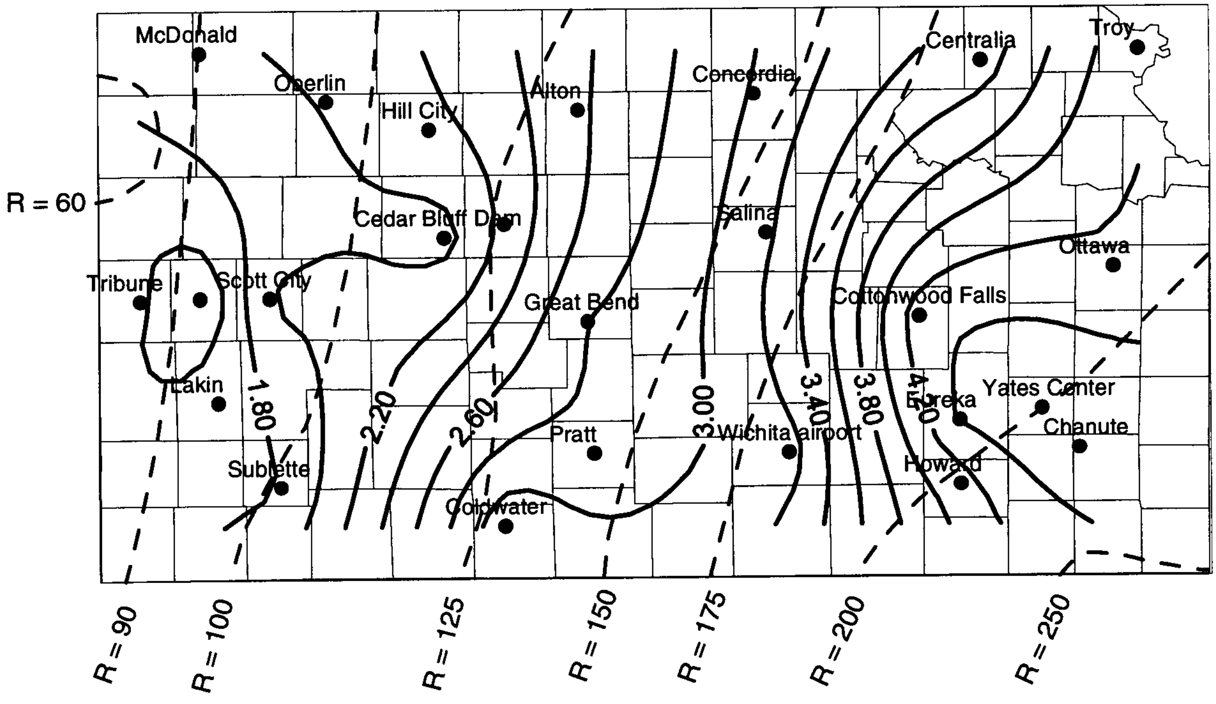

Figure 10–Comparison of soil loss contours in Kansas (kg/m^2) with RUSLE isoerodent lines (dash lines) after parameter smoothing.

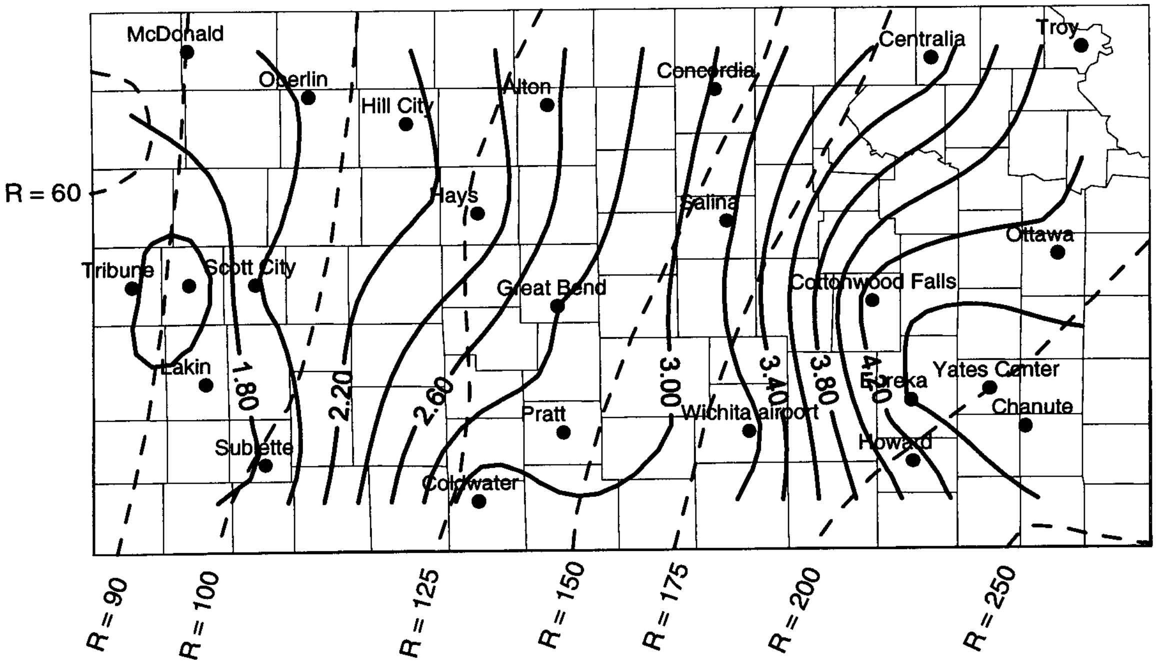

Figure 11–Comparison of soil loss contours in Kansas (kg/m²) with RUSLE isoerodent lines (dash lines) after parameter smoothing, not taking into account the Cedar Bluff Dam station.

value in Pratt was also in agreement with values at neighboring stations. The cluster in the western part of Kansas disappeared and equal soil loss contours were again in the general direction indicated by isoerodent lines. Cedar Bluff Dam had still a particularly low soil loss value that may be caused by local conditions of the measurement station and indicates that the station should not be taken into account within a regional study. When this station was removed (fig. 11), the contours in this region showed similar trends compared to isoerodent lines.

In Virginia, the shape of the equal erosion contours was not significantly changed when parameter spatial averaging was performed (fig. 12). However, because of the very high runoff and soil loss values at the station of Big Meadows, this station was not taken into account to average CLIGEN input parameters. In this case, the smoothing of the parameters at the Big Meadows station would not have been appropriate to obtain consistent regional trends. Similar situations may require the removal of data that clearly create discrepancies in regional trends of average annual soil loss.

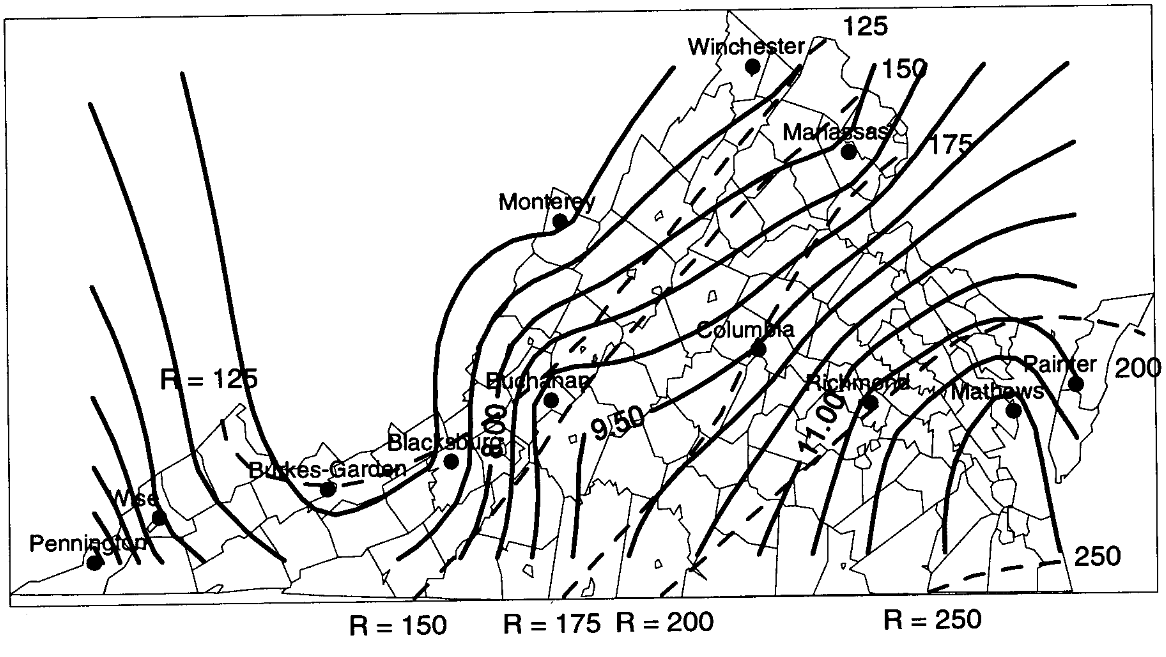

Figure 12–Comparison of soil loss contours in Virginia (kg/m²) with RUSLE isoerodent lines (dash lines) when the Big Meadows station is eliminated and after parameter smoothing.

CONCLUSIONS

CLIGEN and WEPP were run for every station of Indiana, Alabama, Kansas, Colorado, Washington, and Virginia for identical slope, soil, and management conditions within each state. Trends were analyzed by comparing results within one state for different soils and/or management conditions and comparing equal soil loss contours with isoerodent lines.

The results indicated that to obtain a stable running average of the annual soil loss, 30 years of simulation were not enough. In most cases, the minimum simulation period varied between 50 and 100 years with some stations requiring more than 100 years. Therefore, it is best to either determine the adequate period by calculating the running average for each year of simulation, or to choose arbitrarily a minimum period of 200 years. Special attention is required for drier climate. It is recommended to either determine the minimum simulation period or to find a different parameter to characterize erosion since the average annual soil loss may not be appropriate.

Large differences in predicted average soil loss occurred between some stations of the same state. Results that deviated from general trends were easily detected by plotting equal soil loss contours obtained with a kriging technique. Unexpected high or low predicted values resulted in islands or tortuous contours that were very different from the isoerodent lines obtained for the RUSLE equation.

Some variations may have been caused by variations in CLIGEN input parameters due to the different periods and qualities of the samples used to derive them. It may have been that the period of rainfall data used to calculate input parameters to CLIGEN did not represent the general rainfall characteristics over a longer period. This is what may have happened between stations of Indiana or Kansas, states where the climate varies gradually. This variation may also have been the problem for the station of Big Meadows, Virginia, for which twice as much runoff and soil loss was obtained than for the surrounding stations.

Variations may also have been due to very local conditions at the weather sampling station. This may have been the problem in Wichita, Kansas, which is located in a valley, or in Big Meadows, Virginia.

In these two cases, representing such variations was not appropriate when expression of regional trends was desired. One solution was to remove the specific station (as was done with the station of Big Meadows, Virginia). More generally, the smoothing program permitted reducing the variations and expressing only the more regional trends of soil loss variations. Differences of average soil loss values from station to station were reduced and results were more homogeneous throughout these states. As a result, the equal soil loss contours were smoother, contour islands were reduced, and contours and RUSLE R-factor lines showed similar trends.

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