IMPROVEMENT AND EVALUATION OF CLIGEN FOR STORM GENERATION

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ABSTRACT. *The program, CLIGEN, generates peak rainfall intensity and storm duration and other daily weather variables for WEPP to predict the rate of runoff and soil loss. Unrealistic peak rainfall intensity simulated by CLIGEN (version 4.2) led to a discovery of a software bug and subsequent modification of the method to estimate the monthly mean of the maximum 30-min rainfall depth for storm generation. To evaluate the modified CLIGEN, break-point rainfall data for 14 sites in the United States were used for periods varying from 4 to 19 years. The modified CLIGEN was then used to generate weather data for a period of 100 years for the 14 sites. WEPP (version 99.5) was run for the 14 sites, using three soil types for each site, so that the simulated mean annual runoff and soil loss can be compared with those using the observed break-point data. For most (> 96%) of the 42 site-soil combinations tested, there is no significant difference in WEPP-simulated mean annual runoff and soil loss at the 0.05 level between the break-point rainfall data and CLIGEN-generated rainfall data. The bias in the mean is less than 2 to 3% for runoff and soil loss when all sites are considered. The minimum bias in the mean annual runoff and soil loss lends support for the modified CLIGEN to generate input for WEPP for the purpose of runoff and soil loss predictions.*
Keywords. *WEPP, Weather generator, Runoff, Soil erosion, Simulation.*

WEPP represents a new generation of physically based soil erosion prediction technologies (Laflen et al., 1991, 1997; Flanagan and Nearing, 1995), and CLIGEN provides the simulated long-term weather data to determine the rate of runoff and soil loss across the landscape (Nicks et al., 1995). In particular, CLIGEN simulates peak rainfall intensity, an important variable needed by WEPP to calculate the peak runoff rate (Stone et al., 1995; Foster et al., 1995). Peak rainfall intensity profoundly influences the predicted soil loss in WEPP because peak rainfall intensity directly affects interrill erosion, and indirectly affects rill erosion through its effects on peak runoff rate, storm runoff amount and the shear stress. Therefore, adequate reproduction of the intensity characteristics by weather generators such as CLIGEN is crucial to successful soil loss predictions.

Two groups of weather variables are generated by CLIGEN. The first group includes all the daily weather variables such as occurrence and non-occurrence of rainfall, rainfall amount on rain days, daily temperatures and solar radiation. The second group is related to storm patterns on rain days. Other weather generators such as WGEN, WXGEN, and USCLIMATE also simulate daily variables (Richardson and Wright, 1984; Richardson and Nicks, 1990; Hanson et al., 1994). A number of studies have attempted to compare and evaluate these models for weather generation in terms of the quality of the simulated daily variables (Johnson et al., 1996; Wallis, 1993; Wallis and Griffith, 1995; Wilks, 1999). Although there are subtle differences among the various weather generators, CLIGEN is on par with other generators in terms of preserving the low-order statistics of rainfall, temperature, and solar radiation on daily, monthly, and annual bases. Unique to CLIGEN is the capacity to simulate the three additional weather variables to characterize the storm pattern, namely storm duration, time to peak, and peak intensity.

Rainfall amount and these three additional variables are of particular importance for WEPP. In fact, these three variables to define storm patterns were generated especially for WEPP (Nicks and Lane, 1989; Nicks et al., 1995). Nicks and Gander (1994) calculated the R-factor for the USLE for the eastern United States (east of the 105th meridian) and found that, "While there is not exact agreement between the contour lines constructed using CLIGEN and those given in the USLE handbook, the pattern is quite similar. . .". Baffaut et al. (1996) undertook a sensitivity analysis of CLIGEN parameters and concluded that, "The half hour largest intensity and. . . were not found significant for average annual soil loss calculation purposes". Headrick and Wilson (1997) found that CLIGEN was acceptable for five sites in Minnesota in terms of rainfall depth and non-precipitation variables. For rainfall intensity at intervals less than 24 h, the simulated rates were higher than those observed. Because of the uniqueness of the storm generation component of CLIGEN, there have been no comparative studies and little systematic evaluation of CLIGEN in terms of the generated storm pattern and the simulated runoff and soil loss using WEPP.

The objective of this study was to evaluate CLIGEN in terms of simulated runoff and soil loss using break-point rainfall data for 14 sites in the United States. The work reported in this article was prompted by the unrealistic peak intensities simulated by CLIGEN (ver. 4.2). An error in the

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source code was subsequently uncovered, which led to a modification of the method to estimate the monthly mean of the maximum 30-min rainfall depth for storm generation.

BACKGROUND

CLIGEN input parameters have been prepared for 1,078 sites in the United States and are widely available to allow weather generation for input to WEPP. Spatial interpolation of the input parameter values can be used to produce the input file for CLIGEN at other sites if needed. For many other parts of the world, however, raw weather data, including break-point rainfall data, have to be statistically analyzed to prepare the necessary input file to use CLIGEN and subsequently WEPP for soil erosion predictions.

A case in point involves a site in the subtropical region of Australia (lat. 26°04′S, long. 153°48′E). To prepare the input file for this site to run CLIGEN, parameter values for Everglade, Florida (lat. 26°51′N, long. 81°23′W) were monitored to ensure that the calculated model parameter values for the Australian site are of comparable magnitude. One of the required parameters for storm generation in CLIGEN was the average monthly peak 30-min rainfall depth in inches (http://hydrolab.arsusda.gov/nicks/parameters.htm). Baffaut et al. (1996), however, seemed to indicate that it was actually the peak 30-min intensity in inches per hour. In the same article, the authors noted that the predicted rate of soil erosion is insensitive to this intensity parameter, a trend that does not seem to fit comfortably with our established understanding of the soil erosion processes. This conflict in definition of one of the CLIGEN input parameters and the unusual finding of parameter insensitivity led to a close examination of the peak rainfall intensity simulated by CLIGEN. (Subsequent re-analysis of the original 15-min rainfall data for West Lafayette, Station No. 129430, for the period from 1971 to 1996, has shown that the parameter in the CLIGEN input file was in fact the average of the highest monthly maximum 30-min rainfall intensity in inches per hour, although the maximum 30-min rainfall depth should have been used.)

To test the sensitivity of this intensity parameter, the latest version of CLIGEN (ver. 4.2) was run to generate weather data for a period of 10 years. For the Australian site, the average and maximum peak intensity for the 10-year period was 38 mm/h and 250 mm/h, respectively. It was found that the average and maximum peak intensity remained unchanged when the original parameter values were doubled, or when the corresponding values for Everglade, Florida, were used. These strange results led to an examination of the CLIGEN source code for storm generation. A coding error was uncovered that explained why CLIGEN generated the peak intensity independent of the intensity parameter. As for many other bugs in computer software, the cause was actually a simple one. CLIGEN computed a ratio $w = R_{0.5}/R$, where both $R_{0.5}$ and R were rainfall depth (originally in inches). $R_{0.5}$ had been converted from inches into millimeters (mm), while R was not. The resulting w is thus 25.4 times larger than it should be. For most, if not all, sites, the computed w is out of bounds set internally in CLIGEN. The variable, w, thus assumed a constant value of 0.95 for nearly all months and for all sites. The net result of this bug is that for nearly all sites, the peak intensity (in mm/h) is about 3.1 times larger than daily rainfall (mm) on average, and the storm duration is nearly always 3.0 h on average irrespective of the climatic environment for which CLIGEN is used. This bug explains why Baffaut et al. (1996) found that the intensity parameter was unimportant for soil loss prediction and why Headrick and Wilson (1997) noted the considerable overprediction of the rainfall intensity for sites in Minnesota. However, when this simple coding error is corrected, storm duration generated by CLIGEN became excessively long, and the predicted runoff and soil loss using WEPP became unacceptably low. It was therefore decided to modify part of the code for storm generation in CLIGEN, and evaluate the performance of the modified CLIGEN (ver. 5.0) using measured break-point rainfall data.

MATERIALS AND METHODS

WEPP climate input files were prepared using break-point data for 14 sites in the United States (Risse et al., 1995; Zhang et al., 1995a,b; Liu et al., 1997). Break-point data consist of time intervals and the cumulative rain amount for each interval. Rainfall intensity is assumed to be constant within each interval, and there are a series of "breaks" to separate distinct rainfall intensity between adjacent time intervals. Break-point data for these 14 sites were used for this article because they were benchmark sites for other WEPP validation studies and because the climate and other WEPP input files are readily available at http://topsoil.nserl.purdue.edu/. Runoff and soil loss data for these sites were used for either parameter estimation (Risse et al., 1995; Zhang et al., 1995a,b) or WEPP hillslope and watershed validation studies (Zhang et al., 1996; Liu et al., 1997) or both (table 1).

For each storm event, rainfall amount, storm duration, the ratio of time to peak to storm duration, and the ratio of peak intensity to the average intensity were calculated using break-point rainfall data (Risse et al., 1995; Zhang et al., 1995a,b; Liu et al., 1997). The observed maximum and minimum temperatures were used for some sites (Risse et al., 1995; Zhang et al., 1995a,b) and generated using CLIGEN for others (Liu et al., 1997). Other daily weather variables (i.e., solar radiation, wind speed and direction, and dew-point temperature) were all generated using CLIGEN (Risse et al., 1995; Zhang et al., 1995a,b; Liu et al., 1997). Parameter values in the CLIGEN database for the on-site or a nearby weather station were used to generate these other weather variables. The latitude and longitude recorded in the header information of the WEPP climate files were used to determine the weather station that must have been used to provide the additional weather data so that the same set of parameter values were used for this article. Site location, the corresponding weather station, period of record, and long-term mean annual rainfall are summarized in table 1. The long-term mean annual rainfall was calculated as the sum of the long-term mean monthly rainfall. The mean monthly rainfall for month j, R_j, is given by:

$$R_j = \frac{P(W|D)\, N_d\, R}{1 - P(W|D) + P(W|D)} \qquad (1)$$