R-factor Prediction for Australian and the U.S. Sites Using Weather Generators

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Abstract: CLIGEN is a stochastic weather generator to produce daily variables to drive process-based runoff and erosion prediction models such as WEPP. Algorithms were developed to compute the *R*-factor, its monthly distribution, and 10-year storm erosion index (*EI*) needed to apply the revised Universal Soil Loss Equation (RUSLE) using stochastically generated weather variables. Measured *R*-factor and 10-year storm *EI* for 43 sites in Australia and 75 sites in the United States were used to test whether CLIGEN can be used to produce necessary climate inputs for RUSLE. It was found that *R*-factor calculated using CLIGEN-generated weather sequences is well related to the measured *R*-factor for these sites ($r^2 = 0.94$, $n = 118$). In addition, CLIGEN-generated precipitation data can be used to predict 10-year storm *EI* ($r^2 = 0.82$), and monthly distribution of rainfall erosivity for a wide range of climate environments (average discrepancy about 1.9%). CLIGEN can be used to generate a range of climate inputs for runoff and soil erosion predictions. This represents considerable improvement over existing methods to estimate climate inputs for RUSLE.
Keywords: CLIGEN, WEPP, RUSLE, rainfall erosivity

1 Introduction

CLIGEN is a stochastic weather generator to produce continuous daily climate files to run WEPP for runoff and soil loss predictions (Nicks *et al.*, 1995; Flanagan and Nearing, 1995; Laflen *et al.*, 1997). Ten weather variables are generated for each day of the simulation period. The quality of the four precipitation-related variables is of particular importance because previous studies have shown that predicted runoff and soil loss are most sensitive to these precipitation variables (Nearing *et al.*, 1990; Chaves and Nearing, 1991). Yu (2000) tested CLIGEN using break-point rainfall data for 14 sites in the United States in terms of predicted runoff and soil loss. Tests of CLIGEN in terms of runoff and soil loss predicted with WEPP, although highly relevant, were confounded by the fact that specific soil, topography, management, and infiltration and erodibility parameter values have to be used. Performance of CLIGEN was thus conditional upon other input requirements for WEPP. It is therefore desirable to consider other performance indicators that rely solely on rainfall characteristics. If CLIGEN can generate climate data for process-based erosion prediction models such as WEPP, CLIGEN would logically be expected to provide climate input for other erosion prediction models, such as the *R*-factor for RUSLE (Revised Universal Soil Loss Equation, Renard *et al.*, 1997). It is the objective of this paper to use the latest version of CLIGEN to test its ability to generate the *R*-factor, its monthly distribution, and 10-year storm *EI* values for RUSLE for 43 sites in Australia and 75 sites in the United States. This provides a reality check on CLIGEN, and would allow CLIGEN to be used as an appropriate tool for generating climate data for both RUSLE and WEPP in an integrated modeling environment.

2 Data and methods

A total of 43 sites were selected to cover all major climate zones of Australia. The 6 min pluviograph data were used to compute the *R*-factor, its monthly distribution, and 10-year storm *EI* for RUSLE with program RECS (Yu and Rosewell, 1998). The pluviograph data along with daily precipitation data were then used to prepare CLIGEN parameter files for these 43 sites.

Mean annual rainfall, *R*-factor and 10-year storm *EI* values were extracted for 75 sites from the RUSLE database. For each of the 75 sites, a corresponding CLIGEN parameter file was extracted either for the site or for the nearest site.

The metric unit for the *R*-factor is MJ・mm/(ha・h・year), and MJ・mm/(ha・h) for 10-year storm *EI*. Throughout this paper, wherever appropriate "*R*-factor in SI units" instead of '*R*-factor in MJ・mm/(ha・h・year)' is used for simplicity. The same also applies to 10-year storm *EI*. To obtain the *R*-factor in US customary units of hundreds of foot tonf inch $acre^{-1}$・h^{-1}・$year^{-1}$, the *R*-factor in SI units needs to be divided by a factor of 17.02 (Foster *et al.*, 1981; and Renard *et al.*, 1997).

CLIGEN generates four precipitation-related variables for each wet day (Nicks *et al.*, 1995): precipitation amount *P* (mm), storm duration *D* (h), time to peak as a fraction of storm duration, t_p, and the ratio of peak intensity over the average intensity, i_p. In CLIGEN, time is normalized by storm duration, *D*, and rainfall intensity is normalized by the average intensity, *P/D*. Therefore both t_p and i_p are dimensionless variables and they can be regarded as normalized time to peak and normalized peak intensity, respectively.

A double exponential function is used to describe the normalized intensity pattern as:

$$i(t) = \begin{cases} i_p \mathrm{e}^{b(t-t_p)} & 0 < t < t_p \\ i_p \mathrm{e}^{-bt_p(t-t_p)/(1-t_p)} & t_p < t < 1 \end{cases} \tag{1}$$

where *b* is a parameter implicitly depending on t_p and i_p:

$$i_p(1-\mathrm{e}^{-bt_p}) - bt_p = 0 \tag{2}$$

Thus WEPP storm pattern is uniquely defined by the four variables generated by CLIGEN.

For each day when precipitation occurs and when mean air temperature is greater than 0°C, peak 30 min intensity is calculated as follows. If *D* is less than or equal to 30 min, $I_{30} = 2P$ (mm・h^{-1}) by definition. If *D* is greater than 30 min, 30 min peak intensity is given by:

$$I_{30} = \frac{2P\,i_p}{bt_p}\left(1-\mathrm{e}^{-\frac{bt_p}{2D}}\right) \tag{3}$$

The unit energy equation recommended for RUSLE is given by

$$\mathrm{e}(i) = \mathrm{e}_o(1-\alpha\ \mathrm{e}^{-I/I_o}) \tag{4}$$

where e_o = 0.29 MJ・ha^{-1}・mm^{-1}, α = 0.72, and I_o = 20 mm・h^{-1} (Brown and Foster, 1987; Renard *et al.*, 1997). The total storm energy, *E*, can be derived by integrating the unit energy over the double exponential storm pattern:

$$E = P\mathrm{e}_o\left[1-\frac{\alpha\ i_p}{bt_p}\frac{I_o}{I_p}\left(\mathrm{e}^{-\frac{I_p}{I_o}\mathrm{e}^{-bt_p}} - \mathrm{e}^{-\frac{I_p}{I_o}}\right)\right] \tag{5}$$

where I_p is peak intensity (mm・h^{-1}).

The daily storm erosion index, *EI*, is the product of equation (3) and equation (5). These are accumulated for each month, and the *R*-factor, by definition, is the sum of mean monthly *EI* values. A program, CLG2RF, was written to implement the algorithm described above. For any WEPP climate input file(s), including those generated by CLIGEN, CLG2RF calculates daily storm *EI* values whenever liquid precipitation occurs, and outputs (1) mean annual precipitation, (2) *R*-factor and (3) its monthly distribution, and (4) 10-year storm *EI*. The 10-year storm *EI* value is determined from an annual series of maximum storm *EI* values. Each value in the annual series is assigned an average recurrence interval using Weibull's formula (Maidment, 1993). The 10-year storm *EI* value can be determined either directly or using the linear interpolation technique. The program can handle climate data for either single or multiple sites. In addition, users can specify a precipitation threshold below which the storm *EI* values are excluded from calculations.Yu (1999) investigated the effect of using different precipitation thresholds on calculated R-factor and found that the effect can be noticeable, especially for areas with low mean annual precipitation. For this paper, all liquid precipitation was included in *R*-factor calculations. This is consistent with the method used for preparing the isoerodent map for the western United States and with the recommendations for calculating the *R*-factor for RUSLE (Renard *et al*., 1997).

CLIGEN V5.101 (Meyer, 2001) was modified to use random number generators, namely ran1 and gasdev, from Numerical Recipes (Press *et al.*, 1992). This modified version was used to generate climate data for a period of 100 years for each of the 118 sites. Random seeds were selected in the range from 1 to 2^{31}–1, and the random seeds used were recorded for each site so that the results can be readily reproduced if needed.

For these sites in Australia and the United States, standard linear regression technique was used to examine the relationship between measured and generated *R*-factor and 10-year storm *EI*.

Monthly or half-monthly percentage distribution of rainfall erosivity is needed to calculate the weighted cover factor and is also useful for identifying periods of high erosion risk. Two sites each from Australia and the United States were selected to represent a wide range of precipitation regimes. Monthly distribution between observed and generated erosivity using CLIGEN was compared with that for these four sites. It is worth noting that no calibration is required when comparing monthly distribution in terms of percentage contribution to the R-factor. The mean absolute difference in the monthly distribution of the R-factor was used as a measure of the discrepancy between the measured and predicted monthly distributions. This measure has been used to characterize the performance of daily rainfall erosivity models (Yu *et al.*, 2001).

3 Results

Fig.1 shows the relationship between the generated *R*-factor using CLIGEN and the measured *R*-factor for 118 sites in Australia and the United States. The relationship between the two for the 118 sites is

$$R = 0.621 R_{\text{gen}}, \qquad r^2 = 0.94 \tag{6}$$

The coefficient in equation (6) being less than unity indicates that the generated *R*-factor is systematically larger than the measured *R*-factor for these sites. Detailed investigation of the original 6 min data shows that the over estimation is a result of the assumed storm pattern in WEPP and CLIGEN

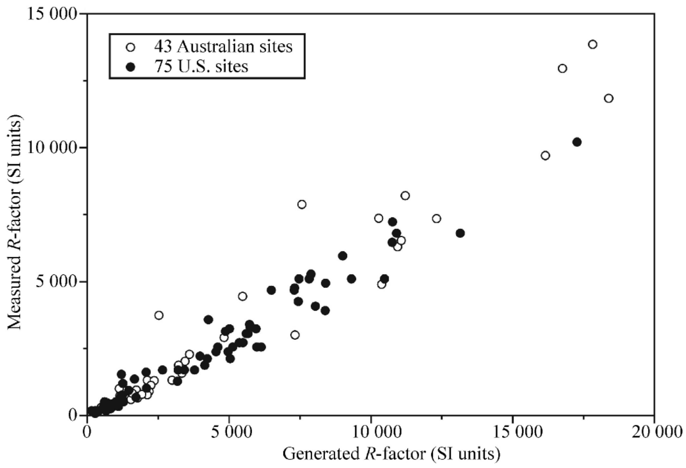

Fig. 1 A comparison between CLIGEN-generated and measured *R*-factor for 118 sites in Australia and the United States.

(results not shown). Equation (6) needs to be used to adjust the *R*-factor generated by CLIGEN. The regression equation for 10-year storm *EI* for the 118 sites is

$$EI = 0.710EI_{\text{gen}}, \qquad r^2 = 0.82 \tag{7}$$

which can be used to predict 10-year storm *EI* using CLIGEN-generated climate data. The relationship for 10-year storm *EI* is not as good as that for *R*-factor as shown in Fig. 2. This is because of the extreme nature of the 10-year storm erosivity with inherently greater variability than the *R*-factor.

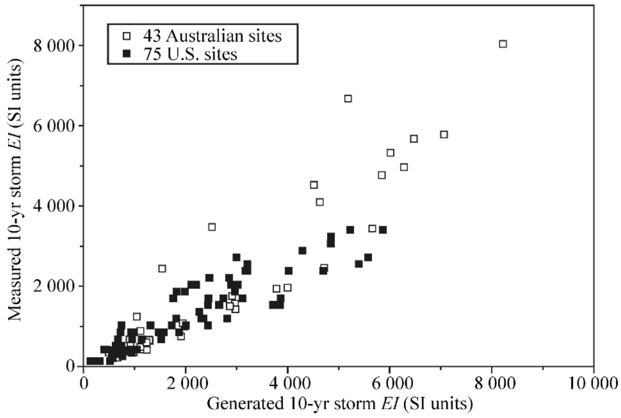

Fig. 2 A comparison between CLIGEN-generated and measured 10-year storm *EI* for 118 sites in Australia and the United States.

Predicted and measured monthly distribution of the *R*-factor is shown in Fig. 3 for four sites. These sites were selected to represent different rainfall regimes in Australia and the United States. It is clear

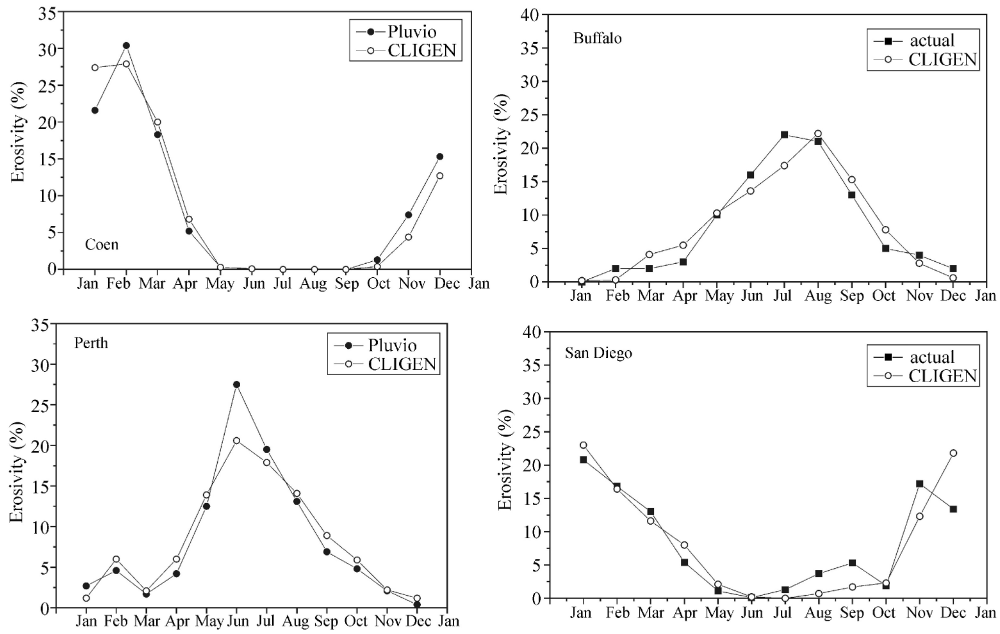

Fig. 3 A comparison of the monthly erosivity distribution for selected sites in Australia and the United States (Coen – Queensland, Australia, tropical summer rain; Perth — Western Australia, temperate winter rain; Buffalo — New York, the U.S., eastern maritime; San Diego- California, the U.S., Mediterranean)

from Fig.3 that the predicted monthly distribution using CLIGEN and CLG2RF captures the seasonal distribution of erosivity for a wide range of precipitation regimes. The discrepancy between measured and predicted monthly distribution averages 1.9% for the four sites.

4 Conclusion

CLIGEN is a useful tool for weather generation because it is relatively simple, it generates a wide range of weather variables, and more importantly, the required parameter values are available for a large number of sites. This paper shows that CLIGEN not only can be used to supply simulated climate data on a daily basis for WEPP, it can also be used as an effective tool to generate the *R*-factor, its monthly distribution, and 10-year storm EI for RUSLE at minimum additional cost. Thus, CLIGEN is able to meet all RUSLE's climate input requirements.

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