Event erosivity factor and errors in erosion predictions by some empirical models

P. I. A. Kinnell

School of Resource, Environmental and Heritage Sciences, University of Canberra, Canberra, ACT 2600, Australia; email: peter.kinnell@canberra.edu.au

Abstract
Analyses undertaken in this paper show that the Universal Soil Loss Equation (USLE) tends to overestimate low values of soil loss when the soil surface has a high capacity to infiltrate rainfall, but the degree of overestimation falls as the capacity of the soil to produce runoff increases. The USLE-M, a version of the USLE that uses the product of the runoff ratio and the EI30 as the event erosivity index, is more efficient in estimating soil loss because runoff is considered explicitly in the event erosivity index, whereas it is not in the USLE. The results show clearly that the problem of the USLE and the RUSLE overpredicting observed erosion losses, when erosion losses are low, is related to a large degree to model formula. In addition, the removal of restrictions to what constitutes a valid EI30 value increases the capacity of the RUSLE to overpredict low soil losses. As the USLE is an empirical model, values of USLE K, C, and P can only be used when the event erosivity parameter is EI30. Models like EPIC ignore this fact.

Additional keywords: rainfall erosion, USLE, RUSLE, USLE-M, EPIC.

Introduction
Risse et al. (1993) observed that the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1965) tended to overpredict observed erosion losses when erosion losses were low and underpredict observed erosion losses when erosion losses were high. Tiwari et al. (2000), in a comparison of the abilities of WEPP (Nearing et al. 1989), the USLE, and the RUSLE (Renard et al. 1997) to predict measured soil loss, noted that all 3 models overestimated low values of measured soil loss and underpredicted the high values. They stated that this phenomenon was inherent to all erosion models. Nearing (1998) suggested that the overprediction–underprediction problem was, in the case of models like the USLE, the result from an inherent mathematical phenomenon associated with regression analysis. However, Kirby and Webster (1999) concluded that Nearing’s analysis was flawed and his examples violate one of the assumptions of regression, namely identical distributions of residuals. In addition, Nearing’s analysis ignored the effect of the model formula on the overprediction of low erosion amounts by models like the USLE. This is illustrated here by comparing modelled soil losses with measured soil losses from bare fallow runoff and soil loss plots in the United States when event soil loss is predicted with event erosivity factors such as EI30 (Wischmeier and Smith 1965) and QREI30 (Kinnell and Risse 1998).

The EI30 and QREI30 event erosivity factors
The USLE was developed to estimate the average annual soil loss using rainfall, soil, topographic, and management data. The equation is:

\[ A = R K L S C P \]  

where A is the computed long-term annual soil loss, R is the rainfall and runoff factor, K is the soil erodibility factor, L is the slope length factor, S is the slope gradient factor, C is the
cover and management factor, and $P$ is the support practice factor. The RUSLE is described by the same equation. Definitions of all symbols used in this paper are provided in Table 1.

The USLE is an empirical model and the primary factor is the $R$ (erosivity) factor. The same applies to the RUSLE. Since, by definition, $L = S = C = P = 1.0$ for the unit plot condition (bare fallow plot of 22.1 m on a 9% slope), the equation for the unit plot is:

$$A = R K$$

(2)

$R$ in both the USLE and the RUSLE depends on event erosivity ($R_e$) through the equation:

$$R = \frac{1}{Y} \sum_{e=1}^{n} R_e$$

(3)

where $R_e$ is given by the product of total rainfall kinetic observed during an event ($E$) and the maximum 30-min intensity ($I_{30}$). $Y$ is the number of years, and $n$ is the number of valid events in $Y$ years. In the USLE, a valid event is a rainfall event that produced 12.5 mm of rain or more or an event that produced 6.25 mm or more in 15 min. These criteria were used for determining $R$ in the RUSLE in the eastern part of the USA, but all storms were considered in determining $R$ in the western part.

In terms of a general empirical equation, Eqn 2 can be written as:

$$A = b R$$

(4)

where $b$ is an empirical coefficient which is equal to $K C L S P$. It follows from Eqns 3 and 4 that, for a bare fallow plot where $C = 1$, the regression equation for the relationship between the predicted event soil loss ($A_{ep}$) and $E I_{30}$ can be written as:

$$A_{ep} = b_1.U (E I_{30})^e$$

(5)

with $b_1.U$ being equal to $K L S P$.

The USLE-M (Kinnell and Risse 1998) uses the product of $E I_{30}$ and the runoff ratio ($Q_R$) as the storm erosivity factor. Thus, for the USLE-M, the regression equation for the relationship between predicted event soil loss and $Q_R E I_{30}$ can, for a bare fallow plot, be written as:

$$A_{ep} = b_{1,UM} (Q_R E I_{30})^e$$

(6)

Since $E I_{30}$ and $Q_R E I_{30}$ are not numerically the same except under completely impervious conditions, $b_{1,UM}$ is not equal to $b_{1,U}$.

Model efficiency analysis

Kinnell and Risse (1998) determined long-term soil and crop factor values for the USLE-M at 14 locations in the United States, using data from USLE runoff and soil loss plot database. The criteria used to determine a valid event in the USLE were ignored in this analysis. Any event that produced runoff and soil loss was considered a valid event. Figure 1 shows the relationships between predicted and observed values for a bare fallow runoff and soil loss plot at one of these locations, Morris, MN, using logarithmic scales. The total loss from the plot was 374 t/ha associated with 80 events over 10 years. As can be seen from Fig. 1, Eqn 5 overpredicts more than 90% of the losses <1 t/ha. The total soil lost for
the 10 events producing the lowest soil losses was 0.83 t/ha. The loss predicted by using Eqn 5 is 25 t/ha.

For data using arithmetic values, the Nash-Sutcliffe model efficiency factor (Nash and Sutcliffe 1970) is determined by:

\[ Z = 1 - \frac{\sum (A_{eo} - A_{ep})^2}{\sum (A_{eo} - A_{me})^2} \]

(7)

where \( A_{eo} \) is the measured or observed soil loss for event \( e \), \( A_{ep} \) is the soil loss given by Eqns 5 or 6, and \( A_{me} \) is the mean soil loss for all the events being considered. \( Z \) has a value of 1.0 when the model accounts for all the variation in \( A_{eo} \). A value of zero indicates that mean

---

**Table 1. Symbols used**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>A, A</td>
<td>Average annual soil loss</td>
</tr>
<tr>
<td>Aeo</td>
<td>Observed (measured) event soil loss</td>
</tr>
<tr>
<td>Aep</td>
<td>Event soil loss predicted by a model</td>
</tr>
<tr>
<td>Alnm</td>
<td>Mean of observed lognormal event soil losses (as opposed to lognormal of the mean observed soil loss)</td>
</tr>
<tr>
<td>b</td>
<td>Regression coefficient in relationship between A and R</td>
</tr>
<tr>
<td>bLU</td>
<td>Regression coefficient for relationship between event soil loss and event EI30 for bare fallow plot</td>
</tr>
<tr>
<td>bLUM</td>
<td>Regression coefficient for relationship between event soil loss and event Q3EI30</td>
</tr>
<tr>
<td>C</td>
<td>USLE cover and management factor</td>
</tr>
<tr>
<td>c2</td>
<td>Event sediment concentration</td>
</tr>
<tr>
<td>DA</td>
<td>Drainage area in ha</td>
</tr>
<tr>
<td>E</td>
<td>Storm rainfall kinetic energy</td>
</tr>
<tr>
<td>GRRup</td>
<td>Gross runoff ratio for a set of rainfall events ignoring those events that do not produce runoff</td>
</tr>
<tr>
<td>ha</td>
<td>Hectare</td>
</tr>
<tr>
<td>I30</td>
<td>Maximum rainfall intensity recorded using 30 min time base</td>
</tr>
<tr>
<td>K</td>
<td>USLE soil factor</td>
</tr>
<tr>
<td>L</td>
<td>USLE slope length factor</td>
</tr>
<tr>
<td>P</td>
<td>USLE support practice factor</td>
</tr>
<tr>
<td>Qe</td>
<td>Event runoff</td>
</tr>
<tr>
<td>QR</td>
<td>Runoff ratio (runoff per unit of rainfall)</td>
</tr>
<tr>
<td>qpe</td>
<td>Peak runoff rate during an event</td>
</tr>
<tr>
<td>R</td>
<td>USLE rainfall and runoff factor (erosivity)</td>
</tr>
<tr>
<td>Rf</td>
<td>Event erosion factor</td>
</tr>
<tr>
<td>ROKF</td>
<td>Coarse fragment factor in EPIC</td>
</tr>
<tr>
<td>S</td>
<td>USLE slope gradient factor</td>
</tr>
<tr>
<td>SYep</td>
<td>Predicted sediment yield for an event</td>
</tr>
<tr>
<td>t</td>
<td>Metric ton</td>
</tr>
<tr>
<td>USLE</td>
<td>Universal Soil Loss Equation</td>
</tr>
<tr>
<td>USLE-M</td>
<td>Modified version of USLE proposed by Kinnell and Risse (1998)</td>
</tr>
<tr>
<td>Xe</td>
<td>Event erosion factor in EPIC</td>
</tr>
<tr>
<td>Y</td>
<td>Number of years</td>
</tr>
<tr>
<td>Z</td>
<td>Nash-Sutcliffe model efficiency factor</td>
</tr>
<tr>
<td>Zgain</td>
<td>Gain in ( Z ) achieved by one model over another</td>
</tr>
<tr>
<td>Zth</td>
<td>Nash-Sutcliffe model efficiency factor for lognormal data</td>
</tr>
<tr>
<td>Zroot</td>
<td>Nash-Sutcliffe model efficiency factor for root 21 data</td>
</tr>
<tr>
<td>Zroot</td>
<td>Gain in ( Z_{root} ) achieved by one model over another</td>
</tr>
</tbody>
</table>
For logarithmic data, the Nash-Sutcliffe model efficiency factor is given by:

\[ Z_{ln} = 1 - \frac{\sum_{i=1}^{n} (\ln(A_{oi}) - \ln(A_{pi}))}{\sum_{i=1}^{n} (\ln(A_{oi}) - \ln(A_{imn}))} \]  

where \( A_{imn} \) is mean of \( \ln(A_{oi}) \) for all the events being considered, and it provides an indicator of the variation shown. \( Z_{ln} \) has a value of 1.0 when the model accounts for all the variation in \( A_{oi} \). A value of zero indicates that \( A_{imn} \) is as effective in accounting for the
variation in $A_{eo}$ as the model. The inability of Eqn 5 ($EI_{30}$) to predict low erosion losses results in a low $Z_{ln}$† (0.084) for plot 10 at Morris, MN.

Equation 6 ($Q_{REI30}$) has a much better capacity to predict low erosion losses ($Z_{ln} = 0.878$). The loss predicted by Eqn 6 for the 10 events producing the lowest soil losses was 1.12 t/ha, an error of just 0.3 t/ha. With respect to the 5 events producing the greatest erosion, Eqn 5 predicted 123 t/ha and Eqn 6 predicted 164 t/ha, whereas the observed loss was 177 t/ha. In this case, Eqn 5 produced a –31% error compared with –7% by Eqn 6.

The gross runoff ratio for runoff producing events ($GRR_{rope}$, total runoff divided by total rain for runoff producing events) for the plot associated with the data in Fig. 1 was 0.195, one of the lowest $GRR_{rope}$ values in the data set, and the gain in favour of using the $Q_{REI30}$ index on this plot was high. Because $Q_b$ has a value of 1.0 for impervious surfaces, values of the $EI_{30}$ and $Q_{REI30}$ indices tend towards each other as the capacity of the soil to produce runoff increases. Consequently, the gain in favour of the $Q_{REI30}$ index decreases with $GRR_{rope}$ (Fig. 2).

As noted earlier, $Z_{ln}$ is more sensitive to soil loss associated with small events than $Z$. The regression for the gain in $Z$ in favour of the $Q_{REI30}$ index is:

$$Z_{gain} = 0.217 - 0.351 \ GRR_{rope} \quad r^2 = 0.129$$

with $P > 0.01$ associated the value of 0.217 and $P > 0.05$ associated with the value of –0.351. The mean values for $Z$ were 0.788 and 0.706 for the USLE-M and USLE respectively.

†$Z_{ln}$ differs from $Z(log)$, the efficiency factor used by Kinnell and Risse (1998). $Z(log)$ is the log-normal transform of the Nash-Sutcliffe efficiency factor, while $Z_{ln}$ is the Nash-Sutcliffe efficiency factor applied to log-normal data. $Z(log)$ is more sensitive to deviations from the model at low values but does not apply to log-normal data.
It should be noted that the analysis undertaken here was undertaken with runoff being a measured parameter. In practice, the performance of the QREI30 index in predicting soil loss on bare fallow plots will usually depend on the accuracy by which runoff can be predicted. Predictions by more process-based models, like WEPP (Flanagan and Nearing 1995) and EUROSEM (Morgan et al. 1998), also depend on the accuracy by which runoff parameters can be predicted. However, the issue here is not the prediction of unknown soil loss but how well a model can account for observed soil losses when parameter values are determined accurately. Apart from issues associated with the inclusion of runoff as a term in the event erosivity index of the USLE-M, in the analyses performed here, the 2 models share errors associated with the determination of EI30 since E was calculated from intensity–kinetic energy relationships (Wischmeier and Smith 1965) rather than measured. Also, the effects of short-term variations in soil erodibility on \( A_{eo} \) caused by, for example, cultivation, are assumed to be random and not to influence the determination of the regression coefficients. This may or may not be so.

**Other indices**

In EPIC (Williams et al. 1984):

\[
SY_{dp} = X_eKLSC_eP_e[ROKF]
\]

where ROKF is the coarse fragment factor as defined by Simanton et al. (1984), \( C_e \) and \( P_e \) are event values for the USLE \( C \) and \( P \) factors, and \( X_e \) is selected from:

\[
X_e = EI_{30}
\]  
\[
X_e = 1.586 (Q_e q_{pe})^{0.56} DA^{0.12}
\]  
\[
X_e = 0.65 EI_{30} + 0.45 (Q_e q_{pe})^{0.33}
\]

where DA is drainage area expressed in ha, \( Q_e \) is expressed in mm, \( q_{pe} \) is peak runoff rate expressed in mm/h, \( EI_{30} \) in MJ.mm/ha.h, and \( SY_e \) is the sediment yield for the event in t/ha (Williams and Arnold 1997). In the data set being considered, data for peak runoff exists for only one plot. Figure 3 shows the observed and predicted soil losses obtained using the \( EI_{30} \) \( (Q_e q_{pe})^{0.56} \) and QREI30 indices for a total 43 events when this plot was cropped with corn in every third year in a meadow–corn–barley rotation. In this case all 3 indices cause low soil losses to be overpredicted. Although some of the variation in observed soil loss results from short-term variations associated with cropping, there are physical reasons why the \( (Q_e q_{pe})^{0.56} \) index performs less well than QREI30. The QREI30 is based on the concept that event erosion is given by the product of event runoff \( (Q_e) \) and sediment concentration \( (c_e) \):

\[
A_e = Q_e c_e
\]

The QREI30 index considers event sediment concentration to vary with the rainfall energy level \( (E \) divided by rainfall amount) and \( I_{30} \) (Kinnell and Risse 1998).

\[
(Q_e q_{pe})^{0.56} = Q_e (Q_e^{-0.44} q_{pe}^{0.56})
\]

so that the \( (Q_e q_{pe})^{0.56} \) index indicates that sediment concentration increases with \( q_{pe} \) but decreases with \( Q_e \). Obviously, the term \( Q_e^{-0.44} q_{pe}^{0.56} \) does not account for variations in the sediment concentrations observed on the plot well, and this is probably because sheet
Fig. 3. Scatter plots of observed and predicted event soil loss for Plot 1 in Expt 1 with corn at Zanesville, Ohio, when predicted = b $R_e$ where $R_e$ is either $EI_{30}$ $(Qq_0)^{0.56}$ or $Q_REI_{30}$ and b is a fitted parameter. The straight lines represents the 1:1 relationships between observed and predicted event soil loss.
erosion, a process where detachment is dominated by raindrop impact, is a major contributor to erosion at the scale used in USLE experiments. However, the index that combined EI30 with \((Q_e \times q_{pe})^{0.33}\) (Eqn 11c) produced an \(Z_{ln}\) value of 0.186, less than associated with the other 2 indices used in EPIC.

One issue of concern associated with Eqns 10 and 11 is the use of same parameter values for \(K\), \(C\), and \(P\), irrespective of which index is used for \(X_e\). The topographic factors for the USLE \((L, S)\) are simply ratios of soil loss from an observed slope length and gradient to that from a 22.13-m-long plot on a 9% slope and can be applied irrespective of the erosivity index used. However, in the USLE:

\[
K = \frac{\sum_{e}^{n} (A_{eo})}{\sum_{e}^{n} (EI_{30})}
\]  

Thus, it follows that if \(X_e\) is changed from EI30, \(K\) for the USLE no longer applies. \(K\) is specific to the event erosivity index and is determined by:

\[
K(X_e) = \frac{\sum_{e}^{n} A_{eo}}{\sum_{e}^{n} X_{e}}
\]  

Also, because:

\[
C = \frac{\sum_{e}^{n} A_{eC}}{\sum_{e}^{n} A_{e1}}
\]

where \(A_{eC}\) is event loss from a cropped plot and \(A_{e1}\) is event soil loss from a bare fallow plot, USLE \(C\) values can only be used with other erosivity indices if those erosivity indices are applied to calculating erosion from bare fallow. If \(Q_e\) and \(q_{pe}\) values for a cropped rather than a bare fallow plot are used, then new \(C\) values specific to the erosivity index need to be determined because they are associated with \(A_{eC}\) not \(A_{e1}\). In the USLE, \(C\) takes account of the effect of the change in runoff between the cropped and bare fallow conditions. If \(Q_e\) and \(q_{pe}\) values for a cropped plot are used, then the effect of the change in runoff is already accounted for in the erosivity index. Kinnell and Risse (1998) presented examples of \(K\) and \(C\) values for use with the \(Q_eEI_{30}\) index. They observed that, for the data they analysed, the ratios of these factors to the USLE factors varied from 1.40 to 3.87 for the soil factor and 1.1 to 32.3 for the crop factor. Consequently, using USLE \(K\) and \(C\) factors with event erosivity indices other than EI30 may result in considerable error in predicting soil loss.

The effect of including all storms when EI30 is used

As noted above, in the USLE, a valid event is a rainfall event that produced 12.5 mm of rain or more, or an event that produced 6.25 mm or more in 15 min. These criteria were used in determining \(R\) in for the RUSLE in the eastern part of the USA but all storms were considered in determining \(R\) in the western part. The analysis undertaken above was restricted to data where runoff occurred. If all storms are considered then EI30 values >0 will occur in some cases when the measured soil loss is zero. Equation 8 cannot be applied when the measured soil loss is zero. Uneven roots can be used as an alternative to using
logarithmic transforms of the data when the measured soil loss is zero. Examination of number of roots showed that, for the relationship between $A_{eo}$ and $EI_{30}$, using the 21st roots of $A_{eo}$ and $A_{ep}$ produces a similar degree of variation as using logarithmic scales (Fig. 4).

In an analysis undertaken here on the Kinnell-Risse US data set (a total of 26 runoff and soil loss plots at 14 US locations), the relationship of $Z_{root21}$ to $Z_{ln}$ for the $A_{eo}$ to $EI_{30}$ relationships for events where $A_{eo} > 0$ was given by:

$$Z_{root21} = 1.04 Z_{ln} \quad (r^2 = 0.996) \quad (17)$$
Also, the regression for the gain in $Z_{\text{root}21}$ in using $Q_{30}EI_{30}$ rather than $EI_{30}$ is:

$$Z_{\text{root}21} \text{ gain} = 0.999 - 1.455 GRR_{\text{rope}} \quad (r^2 = 0.405) \quad (18)$$

with $P > 0.0001$ associated the values of 0.999 and -1.455. The mean values for $Z_{\text{root}21}$ were 0.717 and 0.278 for the $Q_{30}EI_{30}$ and $EI_{30}$ indices, respectively. Eqn 18 is similar to the regression equation for the gain in $Z_{30}$ for the same data (Fig. 2). Consequently, $Z_{\text{root}21}$ can be used as an efficiency measure that is sensitive to the fit of the model to low erosion values in a similar manner as $Z_{30}$.

The current publicly assessable USLE database contains records where one or more of the values for EI$30$, $A_{co}$ or runoff are missing. In the analyses undertaken here, all records containing no EI$30$ values were removed. Then records where both runoff and $A_{co}$ were blank, both runoff and $A_{co}$ were set to zero. Finally, any record where either runoff or $A_{co}$ had a value but the other was blank was removed. Thus, this data set contained events for EI$30 > 0$ but $A_{co} = 0$ and will be referred to as the USLE $A_{co} = 0$ set. This data set provides data to calculate $R$ in a manner that is consistent with the approach used to calculate $R$ in the western United States. In contrast, events where EI$30 > 0$ but $A_{co} = 0$ were omitted from the Kinnell and Risse (1998) data set.

Only 8 of the 26 bare fallow plots identified in the Kinnell and Risse (1998) data set currently exist in the USLE $A_{co} = 0$ set. For these 8 plots, the regression coefficient for the relationship between the gain in $Z$ in favour of the $Q_{30}EI_{30}$ and $GRR_{\text{rope}}$ was -0.378. The regression constant was 0.318. These regression parameters are slightly different from those obtained from the Kinnell-Risse set (Eqn 9). The mean values for $Z$ were 0.800 and 0.640 for the $Q_{30}EI_{30}$ and $EI_{30}$ indices respectively.

Figure 5a shows that the gain $Z_{\text{root}21}$ in favour of the $Q_{30}EI_{30}$ index for the 8 plots in the USLE $A_{co} = 0$ set with respect $GRR_{\text{rope}}$. The mean values for $Z_{\text{root}21}$ were 0.986 and -0.113 for the $Q_{30}EI_{30}$ and $EI_{30}$ indices respectively. The observed $Z_{\text{root}21}$ values are shown in Fig. 5b with respect to the variation in $GRR_{\text{rope}}$

The contrast between the $Q_{30}EI_{30}$ and $EI_{30}$ indices is greatest when $A_{co} = 0$ data are included in the data set. As noted above, the mean values for $R_{\text{root}21}$ were 0.986 and -0.113 for the $Q_{30}EI_{30}$ and $EI_{30}$ indices respectively in this situation. Values below zero indicate that a model is less capable of accounting for the observed variation than the mean. A value of 1.0 results from a perfect model. The gain in $Z$ in favour of the $Q_{30}EI_{30}$ index, though being smaller than the gain in $Z_{\text{root}21}$, is also statistically significant when $GRR_{\text{rope}}$ values are low ($P > 0.01$ for regression constant of 0.318).

Figure 6 shows the gain in $Z_{\text{root}21}$ obtained when $Q_{30}EI_{30}$ and $EI_{30}$ indices are applied to the 8 bare fallow plots common to both data sets when $A_{co} = 0$ data are included compared with when they are not. The mean gain in $Z_{\text{root}21}$ for the $Q_{30}EI_{30}$ index is 0.27. For the $EI_{30}$ index, the mean gain is -0.39. These results indicate that there is a gain in efficiency when the $Q_{30}EI_{30}$ index is applied when $A_{co} = 0$ data are included. There is a decline in efficiency when the $EI_{30}$ index is used. The approach used to determine the RUSLE R values in the western United States involves data sets that contain more $A_{co} = 0$ data than if the original USLE criteria were used. Consequently, the RUSLE must, at least in theory, be less efficient at predicting soil loss in the western United States than in the east.

It will be observed from Fig. 2 that there is little difference between the 2 indices when $GRR_{\text{rope}}$ values are high in the $A_{co} > 0$ set, but this is not the case when $A_{co} = 0$ data are included (Fig. 5). When only $A_{co} > 0$ data are considered and $GRR_{\text{rope}}$ is high, many events
Fig. 5. (a) The gains in $Z_{\text{root}21}$ in favour of the $Q_{\text{REI30}}$ index with respect to $\text{GRR}_{\text{rope}}$ when the $Q_{\text{REI30}}$ and the $\text{EI30}$ indices were applied to data in the USLE $A_{\text{eo}} = 0$ data set where rainfall events producing no erosion were included. (b) $Z_{\text{root}21}$ values with respect to $\text{GRR}_{\text{rope}}$ for the $Q_{\text{REI30}}$ and the $\text{EI30}$ indices in the USLE $A_{\text{eo}} = 0$ data set.

Fig. 6. Gains in $Z_{\text{root}21}$ with $Q_{\text{REI30}}$ and $\text{EI30}$ when $A_{\text{eo}} = 0$ data are included in the data set compared with when not for the 8 bare fallow plots common for both the data sets.
have high $Q_R$ values so that many $Q_R EI_{30}$ and $EI_{30}$ values are close to each other. Consequently, as can be seen by comparing the data for $A_{eo}^{1/21} > 0.8$ in Fig. 7, the deviations from the model values are similar for $Q_R EI_{30}$ and $EI_{30}$. However, when $A_{eo} = 0$ values occur, there are a number of events where the deviation from the model values are great when $EI_{30}$ is used (see values for $A_{eo}^{1/21} = 0$ in Fig. 7a), whereas, because $Q_R = 0$ when $A_{eo} = 0$, no such deviations occur when $Q_R EI_{30}$ is used (Fig. 7b).

Although $Z_{root}^{21}$ emphasises the ability of the models to predict low $A_{eo}$ values, Fig. 2 provides an insight into the comparative performance of the models when $A_{eo}$ values are high. As indicated above, $Q_R EI_{30}$ and $EI_{30}$ values are close to each other when $Q_R$ values are high, and they are not when $Q_R$ values are low. The relationships in Fig. 2 reflect the effect of many events with low $Q_R$ values on eroding areas when $GRR_{rope}$ is low and high $Q_R$ values when $GRR_{rope}$ is high. As a general rule, high $A_{eo}$ values are associated with high $Q_R$ values. Although the trend is for the 2 indices to perform more equally when $A_{eo}$ values are high than when they are low, as illustrated by the data at Morris, MN, the $Q_R EI_{30}$ index will be the better index.
Summary and conclusions

It has been stated (Tiwari et al. 2000) that all erosion models overestimate low values of measured soil loss and underestimate the high values. The analysis undertaken here shows that the USLE tends to overestimate low values of soil loss when the soil surface has a high capacity to infiltrate rainfall, but the degree of overestimation falls as the capacity of the soil to produce runoff increases. Consequently, the efficiency of the USLE to estimate erosion varies with the capacity of the soil to produce runoff. The USLE-M, a version of the USLE, which uses the product of the runoff ratio and the $EI_{30}$ as the event erosivity index, is more efficient at estimating soil loss when soil loss is both high and low because runoff is considered explicitly in the event erosivity index, whereas it is not in the USLE. The results reported here show clearly that the problem of the USLE, and the RUSLE since it also used the $EI_{30}$ index, overpredicting observed erosion losses when erosion losses are low is related to a large degree to model formula. Other event erosivity indices have been used, but as the USLE is an empirical model, values of USLE K, C, and P should only be used when the event erosivity parameter is $EI_{30}$. Models like EPIC ignore this fact so that concern exists about their use in predicting sediment yield. Also, the removal of restrictions to what constitutes a valid $EI_{30}$ value, as done when determining R values for the RUSLE in the western part of the USA (Renard et al. 1997), increases the capacity of the RUSLE to overpredict low soil losses.

References


Manuscript received 2 October 2002, accepted 28 February 2003

http://www.publish.csiro.au/journals/ajsr