Comment on Wang et al (2022), "Calibration, validation, and evaluation of the Water Erosion Prediction Project (WEPP) model for hillslopes with natural runoff plot data"

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Updated 14/12/2022

Letter to the Editor, International Soil and Water Conservation Research

Abstract

Wang et al (2022) undertook an evaluation of the Water Erosion Prediction Project (WEPP) model on 134 USLE runoff and soil loss plots. Wang et al did not compare the capacities of WEPP and USLE based models to predict soil loss. The importance of doing that on bare fallow plots is illustrated here. Data from comparisons of WEPP, RUSLE2, and the USLE-M undertaken by Kinnell (2017) demonstrated that both RUSLE2 and the USLE-M predicted event soil losses on 4 historic bare fallow USLE plots in the USA better than WEPP. It is apparent that because WEPP is a steady state model designed to model event soil loss for ridged tillage cultivation, WEPP is in not well suited to predicting event soil losses from bare fallow plots that are planar with rills occurring in some storms but not all storms. . Given that calibrated WEPP does not model event soil losses on bare fallow USLE plots better than either RUSLE2 or the USLE-M, the fundamental ability of WEPP to model event erosion under natural rainfall must be questioned at this time.

Keywords: WEPP; RUSLE2; USLE-M; calibration; natural rainfall

1. Introduction

The Water Erosion Prediction Project (WEPP) model was developed as a more process-based model than the USLE. WEPP was developed following recognition that the USLE lacked the of ability to deal with rill erosion in a direct manner among a number of other shortcomings. WEPP was specifically designed to predict event soil losses generated by individual rainfall events. The model recognises that detachment by raindrop impact produces soil material that is transported to lines of concentrated flow where rill erosion is driven by flow energy. Detachment within concentrated flow is driven by flow shear acting on the soil surface and is influenced by sediment entering from interrill areas. In WEPP, infiltration, runoff, raindrop and flow detachment, sediment transport, deposition, plant growth, and residue decomposition are considered in respect to determining event soil loss (Flanagan et al., 2007). The WEPP model was developed with the intention of it replacing the official use the USLE modelling approach by the National Resource Conservation Service in the USA. The initial test was undertaken by Tiwari et al. (2000) using 1.600 plot years of runoff and soil loss plot data from 20 different locations in the USA. WEPP recorded a model efficiency of 0.71 compared with 0.80 and 0.72 for the USLE and RUSLE respectively. While the USLE and the RUSLE exhibited better model efficiency (Nash and Sutcliffe, 1970) than WEPP, Tiwari et al. (2000) concluded that this could be attributed to more refined and site specific input parameter for the empirical models. It is apparent that the Wang et al. (2022) paper is an attempt to address that issue by using calibration to ensure the WEPP produced better results than previously obtained on the USLE plots.

Wang et al (2022) undertook an evaluation of the Water Erosion Prediction Project (WEPP) model on 134 USLE runoff and soil loss plots. Even though the work reported by Wang et al may enhance the confidence to the many users of the WEPP model, Wang et al did not compare the capacities of WEPP and USLE based models to predict soil loss. The importance of doing that on bare fallow plots is illustrated here.

2. Theory

A primary objective of the USLE model is the prediction the long-term soil loss from the so called “unit” plot, a bare fallow area 72.6 feet (22.1 m) long cultivated up and down the slope when the slope gradient is 9 %. This enables the USLE model to operate mathematically in two steps. The first step is to predict the average annual soil loss from the unit plot (A_{a1}), where *L, S, C* and *P* all have values of 1.0,

$$A_{a.1} = R\,K \tag{1}$$

The second step modifies that value to take account of conditions which vary from the unit plot,

$$A_a = A_{a.1}\,L\,S\,C\,P \tag{2}$$

This approach means that the physical situation underlying the USLE is a bare fallow area 72.6 feet (22.1 m) long cultivated up and down the slope when the slope gradient is 9 %.

In the USLE, *R* is defined as the average annual value of the product of storm energy (*E*) and the maximum 30-minte intensity (I_{30}),

$$R = \sum_{n=1}^{N} (EI_{30})_n / Y \tag{3}$$

E, storm rainfall energy, was not determined directly but was usually calculated from rainfall energy – intensity relationships based on data on raindrop sizes. In the revised version of the USLE (RUSLE: (Renard et al., 1997)) *E* is determined from

$$e_m = 0.29\,(1- 0.72 \exp(-0.05\, i_m)) \tag{4}$$

where i_m is rainfall intensity in mm h^{-1} and e_m is the energy per unit quantity of rain in MJ ha^{-1} mm^{-1}. Normally, I_{30} is a measured value.

Although it follows from Eq. 1 that K can be considered as the slope of linear regression between event soil losses from the unit plot ($A_{e.1}$) and EI_{30}, in practice, K values were originally determined for the USLE from runoff and soil loss plot data using

$$K = \frac{\sum_{n=1}^{N} (A_{e.1})_n}{\sum_{n=1}^{N} (EI_{30})_n} \tag{5}$$

Determining K using Eq.5 ensures that the sum of the predicted soil losses equals the sum of the observed soil losses.

In the majority of locations where USLE plots were installed, bare fallows plots that conformed to the "unit" plot did not exist. It follows from Eq 1 that

$$A_{a.(C=1)} = R\, k_1 \tag{6}$$

where $A_{a.(C=1)}$ is the average annual soil loss for any bare fallow plot cultivated up and down the slope. It follows from Eq. 5 that

$$k_1 = \frac{\sum_{n=1}^{N} (A_{e.(c=1)})_n}{\sum_{n=1}^{N} (EI_{30})_n} \tag{7}$$

where $A_{e.(c=1)}$ is the event soil loss from the bare fallow plot. K is related to k_1 by

$$K = k_1 / (L\, S) \tag{8}$$

The unit plot provides the primary physical situation upon which the USLE model is based. The equations presented above describe how event soil losses from bare fallow plots underpin the USLE model. However, the two stepped mathematical structure means that any model capable of accounting for event soil losses on bare fallow plots can be used in the first step. WEPP can be considered as a candidate. As demonstrated here, a comparison of the abilities of WEPP, RUSLE2 and the USLE-M reported by Kinnell (2017) is relevant to this proposition.

The work reported by Kinnell (2017) used climate files for WEPP for modelling historic soil losses from bare fallow plots at 8 locations in the USA that were available for a limited time online. These climate files used data on factors such as temperature generated using an early version of Cligen (Nicks et al., 1995) whereas data on rainfall amount, duration, time to peak rainfall and the peak rainfall were generated from existing rainfall records. Originally, the values for factors such as interrill erodibility, rill erodibility, and critical shear stress were calculated using WEPP estimation equations but the effective saturated hydraulic conductivity was estimated by parameter optimization. In order to generate comparisons between the USLE based models and WEPP at these locations, the climate files were updated by Kinnell using Cligen 5.3. The existing data on rainfall amount, duration, time to peak rainfall and the peak rainfall were retained. After updating the climate files, the values for the effective hydraulic conductivity, rill erodibility, and critical shear stress were estimated by parameter optimisation because according to Flanagan et al. (2012), soil losses predicted by WEPP are most sensitive to these three parameters. In order to do this, the WEPP model was run using a range of effective hydraulic conductivity values and value that produced the minimum mean square residual error when the total predicted runoff equalled the total observed runoff for the set of events where runoff occurred was the one selected as the optimum value. Then, the same procedure was undertaken with sets of variations in both rill erodibility and critical shear stress with the focus on the minimum mean square residual error when the predicted soil loss equalled the observed soil loss. Interrill erodibilities were not optimised but maintained at the values set in the validation files because WEPP is not highly sensitive to variations in interill erodibility value (Flanagan et al., 2012). The calibration procedure outlined here was consistent with that recommended by Flanagan et al (2012)

A number of combinations of rill erodibilities and critical shear stress values can generate the desired soil loss outcome of the calibration. For each combination the total of the event soil losses predicted by WEPP was calculated and compared with the total of the observed event soil losses. The combination that produced the closes match with the least mean square error (MSE) was used to generate the WEPP soil loss values used in the comparison between WEPP and USLE based models. As noted above, the procedure for determining soil erodibility in the USLE ensures that the total of the predicted event soil losses matches the total of the observed event soil losses. The procedure adopted by Kinnell (2017) sought to put WEPP on a level “playing field” with the USLE based models in terms of predicting average annual soil loss. The procedure adopted by Wang et al (2022) did not specifically focus on predicting average annual soil loss well.

Two USLE based models were use in the comparison, RUSLE2 (Foster et al., 2013) , and the USLE-M (Kinnell and Risse, 1998). RUSLE2 is currently used by National Resource Conservation Service in the USA. One of the design objectives in the development of WEPP was to produce a process-based model that predicted soil losses as good or as better than the USLE when the USLE is known to work well. The comparison between WEPP and RUSLE2 undertaken by Kinnell (2017) is relevant to testing this objective.

3. Comparison between WEPP and the RUSLE2 in predicting event soil loss on 4 USLE bare fallow plots.

As noted above,, RUSLE2 is currently used by National Resource Conservation Service in the USA. Unlike the USLE, RUSLE2 uses soil erodibility values that vary during the calendar year to take account of variations in the susceptibility of the soil to erosion generated by factors such as temperature and rainfall. Figure 1 shows how RUSLE2 soil erodibility varies temporally on bare fallow plots at the 4 locations considered by Kinnell (2017).

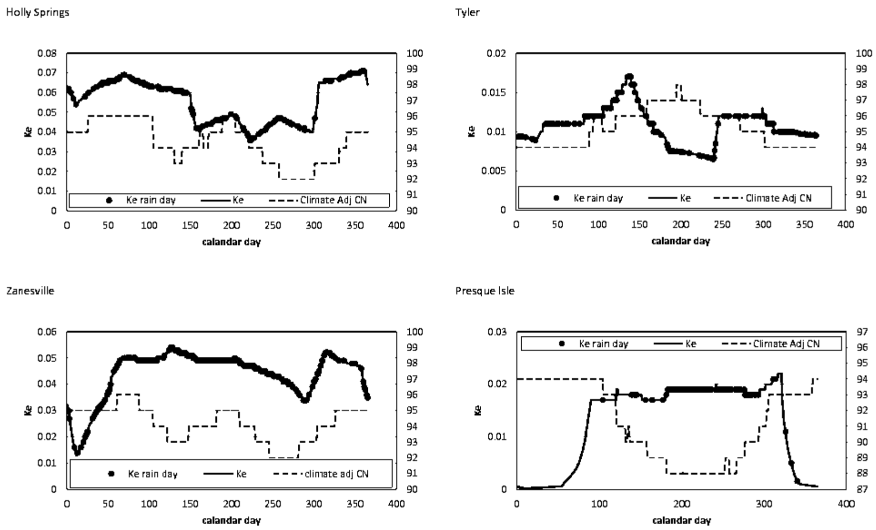

Figure 1.Temporal variability in event erodibility and curve numbers used in RUSLE2 at 4 locations in the USA. The plotted points show the K_e values used in the predictions of bare fallow soil loss for the storms that produced the soil losses recorded in the USLE database.

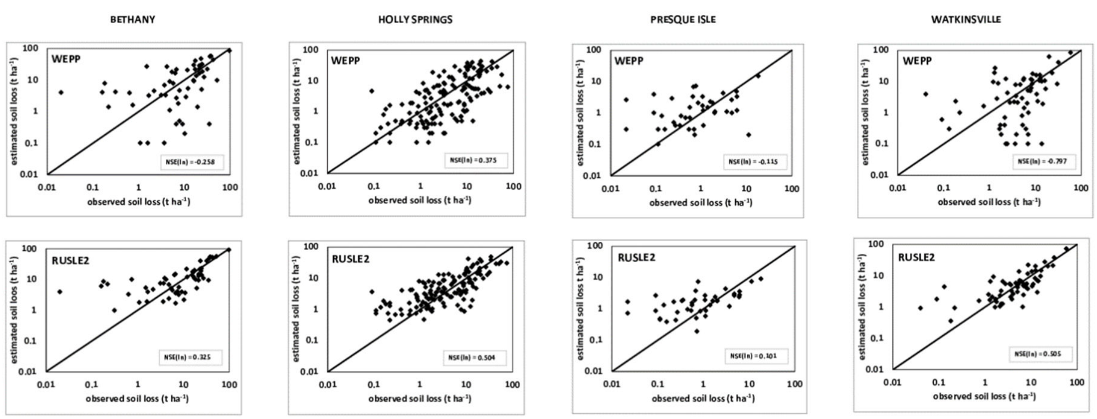

Figure 2. **Relationships between observed and predicted event soil losses associated with the WEPP and RUSLE2 for bare plots at Bethany, MO, Holly Springs, MI, Presque Isle, ME, and Watkinsville, GA. The solid line represents the 1:1 relationship between observed and predicted event soil losses**

Table 1. NSE and NSE(ln) values for calibrated WEPP and RUSLE2 for event soil loss from the bare fallow plots at Bathany, MO, Holly Springs, MI, Presque Isle, ME, and Watkinsville, GA.

	NSE		NSE(ln)	
location	**WEPP**	**RUSLE2**	**WEPP**	**RUSLE2**
Bethany, MO	0.418	0.776	-0.258	0.325
Holly Springs, MI	-0.016	0.531	0.375	0.504
Presque Isle, ME	0.327	0.535	-0.115	0.101
Watkinsville, GA	-0.105	0.752	-0.797	0.505

Figure 2 shows the how the event losses predicted by WEPP and RUSLE2 varied with respect to the observed values. Table 1 shows the Nash – Sutcliffe Efficiency Index values (Nash and Sutcliffe, 1970) for the relationships between the predicted and the measured data and when the logarithmic transforms of the data are considered. NSE(ln) are relevant to the data when, as in Figure 2, logarithmic scales are used. Clearly, RUSLE2 performed better that WEPP in predicting event soil losses at each of the 4 locations.

4. Comparison between WEPP and the USLE-M in accounting for event soil loss on 4 USLE bare fallow plots.

It is well known that event soil loss from runoff and soil loss plots is given by the product of event runoff and event sediment concentration, the soil loss per unit quantity of runoff. The USLE operates on the basis that event sediment concentration varies with EI_{30} per unit of runoff. The USLE-M is based on the observation that event sediment concentration varies with EI_{30} per unit of rain. In respect to this comment, the comparison between WEPP and the USLE-M is the very important because both WEPP and the USLE-M involve direct consideration of runoff in respect to the modelling of event erosion.

Because event rainfall amount divided by event runoff given the runoff ratio (Q_R), the event erosivity factor in the USLE-M is given by the product of the runoff ratio and EI_{30}, Q_REI_{30}. As a result, the soil erodibility factor for the USLE-M (K_{UM}) is given by,

$$K_{UM} = \frac{\sum_{n=1}^{N} (A_{e.1})_n}{\sum_{n=1}^{N} (Q_R EI_{30})_n} \qquad (9)$$

For any bare fallow plot with cultivation and down the slope

$$A_{e.(C=1)} = k_{UM1}\, Q_R EI_{30} \qquad (10)$$

where

$$k_{UM1} = \frac{\sum_{n=1}^{N} (A_{e.(c=1)})_n}{\sum_{n=1}^{N} (Q_R EI_{30})_n} \qquad (11)$$

Table 2. NSE and NSE(ln) values for calibrated WEPP, the USLE-M using runoff predicted by WEPP and the USLE-M for event soil loss from the bare fallow plots at Bethany, MO, Holly Springs, MI, Presque Isle, ME, and Watkinsville, GA.

	NSE			NSE(ln)		
location	**WEPP**	**USLE-M with WEPP runoff**	**USLE-M with obs runoff**	**WEPP**	**USLE-M with WEPP runoff**	**USLE-M with obs runoff**
Bethany, MO	0.418	0.591	0.754	-0.258	0.317	0.81
Holly Springs, MI	-0.016	0.562	0.659	0.375	0.605	0.706
Presque Isle, ME	0.327	0.673	0.899	-0.115	0.296	0.812
Watkinsville, GA	-0.105	0.356	0.489	-0.797	0.362	0.548

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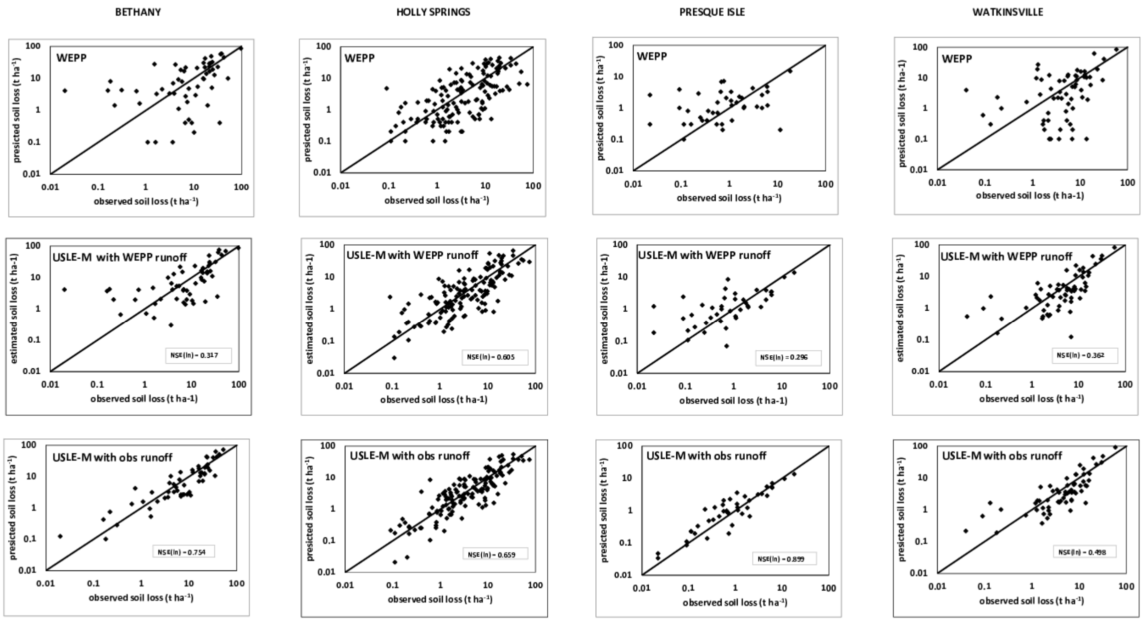

Figure 3. **Relationships between observed and predicted event soil losses associated with the WEPP and USLE-M for bare plots at Bethany, MO, Holly Springs, MI, Presque Isle, ME, and Watkinsville, GA. The solid line represents the 1:1 relationship between observed and predicted event soil losses**

Figure 3 shows the how the event losses predicted by WEPP and the USLE-M varied with respect to the observed values. Table 2 shows the Nash – Sutcliffe Efficiency Index values for the relationships between the predicted and the measured data and when the logarithmic transforms of the data are considered. WEPP can only predict event soil loss when runoff is predicted and, as in the case when WEPP and RUSLE2 was compared, the USLE-M using the $Q_R EI_{30}$ index with runoff predicted by WEPP outperformed WEPP at each of the 4 locations considered. The improvement in the Nash – Sutcliffe Efficiency Index values when the $Q_R EI_{30}$ index is determined using observed runoff illustrates the impact on WEPP of the inability of WEPP to predict event runoff well. Comparisons of the abilities of WEPP and the USLE-M to predict event soil loss on steep (17% to 53%) runoff and soil loss plots at the Ansai Research Starion in China (Kinnell et al., 2018), demonstrated the superiority of the USLE-M to predict soil loss in situations where rilling frequently occurred during rainstorms.

5. Discussion

The comparisons made between WEPP, RUSLE2 and the USLE-M described above lead to the question

Why does WEPP, a model specifically designed to predict event soil loss, preform less well than USLE base models in accounting for event soil losses on bare fallow USLE plots ?

One answer is that WEPP is a steady state model designed to model event soil loss for ridged tillage cultivation. However, USLE bare fallow plots are planar with rills occurring in some storms but not all storms. It seems that the calibration undertaken by Kinnell (2017) did not overcome the mismatch between the physical situations for which WEPP was designed and the physical satiations that occur on the USLE bare fallow plots.

In terms of the desirability to predict event soil losses better than can be done using the existing USLE models, obviously it is appropriate to focus on the capacity of the soil loss model to predict event soil loss under natural rain when runoff is known before looking at means to predict runoff which is necessary for the model to be used to predict soil loss when runoff is not measured. The current version of WEPP does not enable soil loss to be modelled when runoff is measured.

There is no doubt that having a capacity to predict event soil losses in cropped areas is desirable since it provides a capacity to deal with factors that influence soil loss in the short term. Having a good ability to model event soil loss on bare fallow runoff and soil loss plots provides confidence in the ability to model erosion in cropped areas provided the effect of the difference in runoff production between cropped and bare fallow areas is taken into account. Currently, the C factor in the USLE model is responsible for this in the long term but does not deal with the issue well in modelling event erosion in cropped areas because the USLE model was not designed model event erosion in cropped areas. Although calibrated WEPP was applied by Wang et al (2022) to predicting event soil loss on both bare fallow and cropped plots, comparing the abilities of WEPP and USLE based models to predict soil loss from cropped plots is beyond the scope of the comparisons made using the data obtained by

Kinnell (2017). However, it is possible to use runoff from cropped areas to determine Q_R and enable the $Q_R EI_{30}$ index to be used to predict event soil loss on cropped areas (Kinnell and Risse, 1998).

One of the reasons why WEPP was developed was that although rill erosion is acknowledged to enhance soil loss in comparison to when sheet erosion occurs, the EI_{30} index does not take into account the fact that rill erosion is a flow driven rather raindrop impact driven process. Given that rilling was not monitored on USLE runoff and soil loss plot, the fact that rilling enhanced soil loss is one of the factors that contributed to the difference between predicted and observed event erosion values when either the EI_{30} index or the $Q_R EI_{30}$ index is used in predicting event soil loss on bare fallow plots. In theory, separate soil erodibility values can be used for storms that generate just sheet erosion and storms that produce rill erosion (Kinnell et al., 1994) but lack of monitoring of rill erosion on runoff and soil loss plots does not facilitate that approach to be developed using data from the historic bare fallow USLE plots.

6. Conclusion

WEPP was designed to predict event soil loss. In effect, the calibrations performed by both Kinnell (2017) and Wang et (2022) result in WEPP becoming just another empirical model in the context of accounting for event soil losses on bare fallow runoff and soil loss plots. WEPP is also just another empirical model when WEPP is specifically calibrated for each cropping system period on each plot at each location. Given that calibrated WEPP does not model event soil losses on bare fallow USLE plots better than either RUSLE2 or the USLE-M, the fundamental ability of WEPP to model event erosion under natural rainfall must be questioned at this time.

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