EFFICIENCIES OF MANAGEMENT PRACTICES IN EROSION CONTROL AT CONSTRUCTION SITES

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Abstract
Soil erosion is a widely recognized global problem. New techniques are continually being developed to minimize adverse impacts of soil erosion, specifically those resulting from human activities. Mathematical modeling plays a vital role in this process; i.e. development and continual improvement of such techniques. Mathematical modeling provides an avenue to understand and express the processes involved in soil erosion. Use of mathematical models to simulate the se processes enables scientists, planners and decision makers to predict erosion with relative ease even in the midst of constantly shrinking resources. This, in addition to the recent advancement in computer technology, has given rise to the development of a series of soil erosion models. The Universal Soil Loss Equation (USLE) is one such model. An empirical model, USLE was developed specifically to estimate average annual soil loss from agricultural fields. Due to its ease of use and reliability, USLE has been accepted around the world resulting in its widespread use. Since its development in the 1970s, this model has gone through a number of improvements, resulting in the Modified-USLE (MUSLE) and Revised-USLE (RUSLE) models. Originally developed to predict average annual soil loss from agricultural fields, RUSLE can be extended to simulate soil loss from construction sites resulting from individual storm events. Effects of various management practices can then be superimposed to construct a mosaic that can be used to propose the most effective (i.e. best) management practices for specific sites with varied soil type and topography. This paper presents the results of such a study using large-scale rainfall simulators (efficacy of use of rainfall simulators is presented elsewhere in this conference proceedings) with the principal aims of calibrating and verifying RUSLE for two different soil types in the Eastern New South Wales in Australia. The outcome will be a series of recommendations (based on the efficiencies of various management practices) that balance the developmental needs and economic constraints.

Additional Keywords: RUSLE, grass strip, silt fence, gravel bag, soil erosion

Introduction
Human population has increased in exponential fashion over the last three quarters of the century leading to rapid exploitation of natural resources beyond its renewal capacity (Hudson, 1995). Soil is not an exception of this. Natural rate of soil erosion is increased exorbitantly due to the increase in agricultural activities. Mine exploration and massive construction activities heavily disturbed the natural state of the soil (Morgan, 1995). Use of chemical fertilizers increased the erosive potential of the soil This further increased the rate of soil erosion.. As a non-renewable resource at human time scale, the masking effect of improved technology to enhance productivity became questionable as it lead to the negative effects of permanent desertification. Only 11% of the global land considered as productive should feed 7600 million people by 2020 (Eswaran *et al*., 2001). A large portion of the sediment particles carried by natural river system is discharged at the ocean causing the seashore land to be more vulnerable to impoundment. So the land degradation has been a serious environmental issue and will remain as a problem in the 21st century.

More than 80% of land degradation is due to soil erosion out of which 56% is due to the water induced soil erosion (Oldeman, 1992). UN Environmental Program reports that crop productivity on about 20 million hectares each year is reduced to zero or becomes uneconomical because of soil erosion or soil induced degradation (UNEP, 1991). Human induced degradation has affected 24 percent of inhabited land area (Oldeman, 1992).

Soil erosion has both onsite and offsite effects. Reduction in the productivity of the agricultural land by removal of fertile top soil and depletion of root depth of crops, formation of undulations in land surface due to the formation of rill and gully, inundation of vegetation from the land surface, scouring of the foundations of hydraulic structure, road and other infrastructures are some examples of the immediate onsite effects caused by the soil erosion (Morgan, 1995). Offsite effects include unnecessary sediment deposition over the cropland, extreme pollution of water bodies, sedimentation in the storage reservoirs, channel bed and road drainage structure (Morgan, 1995). Construction sites are significant source of sediment and other non point source pollution. Soil erosion from construction sites, without proper soil erosion and sediment control practices can average between 20-200 tones $acre^{-1}year^{-1}$, which is 10 to 20 times greater than typical losses from the agricultural land (NRCS, 1999). Soil erosion from construction sites thus is more severe in terms of intensity than from agricultural land and degrades land more rapidly. Chemicals used in the construction sites and mined land and carried out with eroded soil and water may be poisonous to aquatic life, human and vegetation. Thus soil erosion has multifold effects in natural environment. This is a serious problem for sustainable future of our nature and the environment.

Universal Soil Loss Equation, USLE (Wischmeier and Smith, 1978), later revised as Revised USLE, RUSLE (Renard *et al*., 1996) is one of the empirical models developed in the USA with more than 10,000 plot years of research data and experience of soil scientists to estimate soil erosion in annual basis from the hillslope. The model was selected for the study as it is easy to use yet giving acceptable results from the construction sites. Parameter estimation is relatively easy and well-explained documentation is available (Renard *et al*., 1996). Calibration and validation of some parameters were made using data from erosion plot experiments carried out in NSW. Calibrated parameters were used to evaluate the efficiencies of some mechanical techniques of erosion control from the construction sites.

Materials and Methods

Calibration and validation of RUSLE was carried out using the data from the erosion plot experiments carried out at Penrith campus of the university and at the Gosford, NSW. The rainfall intensities used in this experiment were to be representative of the low (one year average recurrence interval (ARI)) to medium (five to 10 year ARI) with 30-minute rainfall duration. The intensities were obtained using IFD curves of selected sites published by the Bureau of Meteorology (IEAust, 1987). It was expected that the 30 minute duration would provide enough time to capture all components of hydrographs. Times of concentration for the plots for Penrith area was estimated as 10 minutes and that for Somersby was estimated as 15 minutes (Shrestha, 2002).

Erosion plots of 80m length were constructed to represent general length of the land employed in the housing project construction sites in NSW. The width of the plots were kept to 5 m, to avoid boundary effects. Slopes of the sites were varied between 7% or 8%. Three different treatments: Rotary hoed, rolled smooth and topsoil restored were employed to represent general construction site land use condition. Sediment collection troughs were installed to collect sediment and runoff water from the experiment. Two standardized RBC flumes (B_c=75 mm and B_c=150 mm) were prefabricated and installed at the plot outlet downstream of the collection trough to measure runoff from each of the plots. These flumes were laboratory tested before commencement of the experiments to ensure verification of calibration results provided by Bos (1991). Every care has been taken while constructing the plots to avoid the influence of external factors during the simulation and the erosion processes. Access roads and boundaries were constructed around the plots.

Large-scale pressure sprays rainfall simulators were used in this study. Recommended pressure and nozzle combinations from the calibration study of the rainfall simulator carried out by Farre (2001) were used for the rainfall simulation. Runoff was measured using the RBC flumes at the outlet of collector apron. Discharge was measured in 30 second or one minute interval, manually by reading the stilling well. Time of the beginning of storm and commencement of runoff was also recorded. Runoff hydrograph is plotted for each run of experiment for each plot. Soil samples were collected from three different locations of each plot before and after experimental runs to enable estimation of the change in soil moisture. The samples were stored inside the core casings sealed with core caps and weighted. The cores were then oven dried at 104°C for 24 hours until complete dryness was achieved. Then bulk density and moisture content of soil were estimated.

NSW Department of Infrastructure, Planning and Natural Resources (DIPNR) carried out the detailed soil analysis and the results provided by the department were used in the model. Model parameters such as organic mater content, percentage clay, percentage silt, percentage sand and percentage rock fragment were also obtained from the detail soil analysis conducted by DIPNR. Soil permeability and soil structure class parameters were estimated using the guideline given in SOILOSS (Rosewell, 1993). All these soil parameters were used to calculate soil erodibility factor K of RUSLE model.

Runoff water was carefully collected at one-minutes interval in clean and washed polyethylene bottles of 500 ml capacity. The collection point was the outlet of the apron. Sediment samples thus collected were filtered. The results were used to generate sedigraph (a plot of sediment concentration vs time), which gives the picture of sedimentation concentration over the experimental run. Sedigraphs were used along with the hydrograph to estimate total soil loss exit from the outlet of the collection trough. Considerable amount of sediment was deposited in the collection trough, which was not counted in the sedigraph. Volumetric measurement of the sediment deposited between the outlet of the apron (where sample for sedigraph was taken) and outlet of the experimental plot was carried out after runoff ceased. The total quantity of soil eroded during experimental run was computed as the sum of these two components: from the sedigraph and hydrograph and from the collection trough.

RUSLE estimates the average annual soil loss from the entire hillslope. The equation is given as:

$$A = R \times K \times LS \times C \times P \qquad (1)$$

where,

A = Average annual soil loss predicted (t ha^{-1}), R = Rainfall runoff erosivity factor (MJ mm (ha h)$^{-1}$), K = Soil erodibility factor, (ton ha h (MJ ha mm)$^{-1}$), L = Slope length factor, S = Slope steepness factor, C = Cover management factor and P = Support practice factor

Rainfall runoff erosivity factor R, in RUSLE represents the impact of rainfall energy in erosion. Rainfall energy per unit depth of rainfall e_k (MJ ha^{-1} mm^{-1}) was determined using the equation suggested by Rosewell and Turner (1994) given by:

$$e_k = 0.29\left(1 - 0.596 e^{(-0.04 i_k)}\right) \qquad (2)$$

where:

i_k = Intensity of rainfall (mm h^{-1})

The total rainfall energy of single storm is computed as

$$E = \sum_{k=1}^{p} e_k d_k \qquad (3)$$

where:

d_k = Depth of rainfall for k^{th} interval of the storm (mm), p = Total no of intervals in the storm

Finally R is estimated by the relation

$$R = E \times I_{30} \qquad (4)$$

where:

I_{30} = Maximum 30 minute intensity (mm h^{-1})

As rainfall simulators were used in the experiment with constant intensity throughout the experimental period, I_{30} is equal to the average intensity. Each of the simulation was carried out for 30 minutes resulting in the depth of the rainfall as half of intensity. R factor in this case, hence reduces to:

$$R = 0.145(1 - 0.59 e^{(-0.04 i)}) i^2 \qquad (5)$$

where:

i = Measured average rainfall intensity (mm h^{-1})

Eq. 5 was used to estimate R factor value from each of the experimental runs in this study.

Soil erodibility factor, K, is estimated from the approximated equation of the nomograph developed by USDA-ARS (Renard et al., 1996) as total percentage of silt and fine sand did not exceed 70% and given as:

$$K = 2.77 \times 10^{-7} \left(12 - OM\right) \cdot M^{1.14} + 4.28 \times 10^{-3}\left(s - 2\right) + 3.29 \times 10^{-3}\left(p - 3\right) \qquad (6)$$

where:

K = Soil erodibility factor (ton. ha. h MJ^{-1} ha^{-1} mm^{-1}), s = Soil structure class (1-4), p = Soil permeability class (1-6), OM = Percentage organic matter content and M = Product of primary particle size fraction given as (Rosewell, 1993)

$$M = \left(si + 0.7 Fs\right)\left(si + Fs + Cs\right) \qquad (7)$$

where:

si = Percentage silt, Fs = Percentage fine sand Cs = Percentage coarse sand

As the research plots used in the experiment satisfied the requirements of USLE plot, the equation developed by USDA, ARS to estimate LS factor were used. The equations used to estimate L factor for hillslope of length λ were:

$$L = \left(\frac{\lambda}{22.1}\right)^m \qquad (8)$$

where:

m = Variable slope length exponent.

The value of slope length exponent depends upon the ratio of rill to interrill erosion. If β is the ratio of rill erosion to interrill erosion then m is given as

$$m = \frac{\beta}{(1+\beta)} \tag{9}$$

For moderately susceptible soil in both rill and interrill erosion, McCool et al. (1989) suggest the equation:

$$\beta = \frac{11.1607 Sin\psi}{3.0\left(Sin\psi\right)^{0.8} + 0.56} \tag{10}$$

where:

ψ = Slope angle (degrees)

Renard et al. (1996) suggested to double the value of β obtained from the above equation to compute the slope length exponent, *m*, if the soil is highly susceptible to rill erosion like in case of freshly prepared steep construction slopes. As all the experiments in this study were carried out on bare soil to represent urban construction sites, value of β was doubled before applying it to compute exponent *m*.

S factor is the slope steepness factor and represents the effect of slope in erosion given by the relation (McCool *et al.*, 1987).

$$S = \begin{cases} 10.8 Sin\psi + 0.03 & for \quad slope < 9\% \\ 16.8 Sin\psi - 0.50 & for \quad slope \geq 9\% \end{cases} \tag{11}$$

where:

ψ = Slope angle (degrees)

This equation was used to compute *S* factor and value of *L* and *S* were combined to get the value of *LS* factor.

Value of measured soil loss A, and estimated values of R, K and LS from the above equations were used to estimate combined value of cover management factor *C* and support practice factor *P*, known as CP and given by the relation:

$$CP = \frac{A}{(RKLS)} \tag{12}$$

Half of the data from the experiment from each plot were randomly selected for the calibration of CP and remaining half were used to validate the calibrated value. After validation, calibrated CP values from each of land use condition were used to determine the efficiency of three different support practices.

Results and Discussion

Toy and Foster (1998) recommend that for the scalped surface, value of *C* is 0.15. As no specific support practices were adopted in plot one of each site and land surface was rough to disturb the flow, *P* factor in this case can be considered to be in the range of 0.7-0.8. This gives *CP* ranging 0.11 to 0.12. The calibrated value of *CP* for Penrith soil is 0.13 while that for Somersby is 0.07. Similarly, *CP* value for plot three (topsoil restored, representing partially filled construction site) was estimated as 0.23 and 0.32 for Penrith and Somersby respectively. Toy and Foster (1998) suggest *C* value for complete fill condition ranging from 0.85 to 1.00. For partially filled condition, value of *C* can be taken to be 0.4 to 0.5. Similar support practice value as in plot one can be considered in this case, ranging *P* value from 0.70 to 0.80. This gives the range of *CP* from 0.28 to 0.40. *P* value suggested in different literature (Renard et al., 1996; Rosewell, 1993; Morgan, 1995) for scraped and rolled smooth condition as in plot two is 1.0. But *C* value for the scraped surface with undisturbed soil and compacted with roller can be taken ranging from 0.15 to 0.20, giving the range of *CP* from 0.15 to 0.20. Estimated *CP* for this condition ranges from 0.12 to 0.26. This shows that calibrated values of *CP* seem reasonable when compared with the values published in different literature.

The validation of the calibrated *CP* values was carried out by using *CP* values as input to the model. Predicted soil loss from the model was compared with corresponding value of measured soil loss. Figure 1 & 2 gives the scatter plot of predicted vs measured soil loss (R^2=0.85) and calibrated *CP* vs measured *CP* (R^2=0.83) respectively.

There were less than 15% differences in most of the soil loss prediction results in comparison to measured values. Model over predicted soil loss some of the cases. The highest over-prediction was observed in run one of plot three for Somersby site, resulting in 204.5% more soil loss from the measured value. Very low runoff of 0.2mm was recorded in this experiment, although the rainfall intensity applied was 43mm h^{-1}, giving *R* factor as 238 MJ mm (h ha)$^{-1}$. This implies that although there was a significant splash erosion causing soil detachment (*R*=238 MJ mm (ha h)$^{-1}$, higher infiltration (42 mm h^{-1}) caused very low flow, reducing the measured soil loss. RUSLE is not a spatial model and does not estimate soil deposition separately. All the detachment was accounted in the soil loss prediction by the model. But due to the low surface flow, significant quantity of detached particles were deposited within the plot and not accounted in the measured soil loss. This is a valid argument as model over predicted soil erosion in most of the cases. Some deposition is always expected within the plot irrespective of the applied rainfall intensity and runoff produced in the hydrograph recession when the rainfall ceases. This is because of the decrease in flow. Majority of the results support the validity of model leading to usefulness of the calibrated parameters.

Table 1. Measured and Predicted soil loss with different support practices

Site	Land use condition	Rainfall intensity (mm/h)	Measured soil loss (t/ha)	Calibrated CP	Predicted soil loss (t/ha)	Predicted soil loss (t ha^{-1}) with		
						Short grass strip (P=0.55)	Gravel bags (P=0.37)	Silt fences (P=0.15)
Penrith	Rotary hoed	62	3.45	0.13	3.42	1.88	1.27	0.51
		72	4.67		4.70	2.59	1.74	0.71
	Rolled smooth	28	1.23	0.26	0.81	0.44	0.30	0.12
		67	2.72		5.62	3.09	2.08	0.84
	Topsoil restored	46	3.09	0.32	3.20	1.76	1.19	0.48
		57	5.20		5.02	2.76	1.86	0.75
Somersby	Rotary hoed	76	3.14	0.07	2.78	1.53	1.03	0.42
		74	2.30		2.63	1.45	0.97	0.39
	Rolled smooth	87	6.19	0.12	6.18	3.40	2.29	0.93
	Topsoil restored	44	2.91	0.23	2.94	1.62	1.09	0.44
		70	7.96		7.87	4.33	2.91	1.18

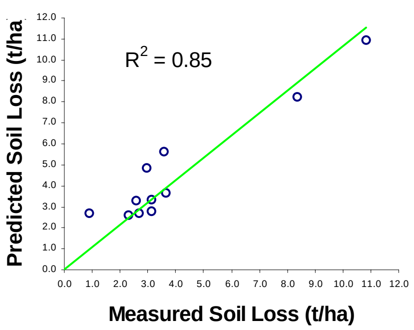

Figure 1. Measured vs predicted soil loss

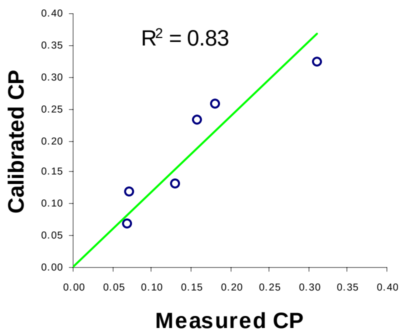

Figure 2. Measured vs predicted *CP*

Cover management factor *C* and support practice factor *P* are the two factors that can be modified by adopting suitable land use and support practices if the soil loss predicted is above the tolerance. But generally in the construction sites, changing the value of cover management factor such as increasing ground cover, mulching or increasing surface roughness are impractical. Then choosing suitable support practices such as buffer strips, establishing barriers etc, will be the best alternatives for erosion control. In such cases, reasonable value of cover management factor *C* and support practice factor *P* need to be determined from the recommended *CP* value. Desirable support practices can be adopted based on the *P* factor value computed.

Sometimes if single support practice is insufficient to reduce soil erosion to tolerable limit, more than one practice can be implemented. In such cases *P* factor values from each support practices can be multiplied to get final effective *P* factor (Toy and Foster, 1998). Toy and Foster (1998) recommended for the slope condition ranging from 5-10%, *P* value for Short grass strip, gravel bag and silt fences can be taken as 0.55, 0.37 and 0.15 respectively. Using these values with the calibrated *CP* values it has been found that soil erosion can be reduced by about 45% from each site if short grass strips are employed as support practice. Gravel bags are more effective in soil erosion control, reducing the value by over 60%. Results also show that the silt fence is the most effective support practice and can reduce soil erosion by over 85%. It is important to note that the efficiency of practice factors will vary as the shapes change.

Conclusions

An attempt of calibration of RUSLE to use it in construction sites in NSW is deemed successful as calibrated parameters successfully tested for their validity (R^2=0.85). The parameters will be useful in estimating soil erosion from construction sites of NSW. The study also confirmed that RUSLE can be used to predict soil erosion from construction sites from single storm rainfall of particular intensity. Suitable management practices can be adopted to reduce soil erosion to a tolerable limit. Model can also be used to observe sensitivity/effectiveness of particular support practice in erosion control. It has been identified that support practices such as short grass strip, gravel bag and silt fence are very effective erosion control devices reducing soil erosion in the range of 45% to 85%. These support practices can be regarded as best management practices (BMPs) as they are efficient and environment friendly. Large-scale rainfall simulators are fairly accurate in representing natural storms and can be used in the calibration of more process based erosion prediction and hydrologic models such as WEPP.

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