error was shown to be a function of the number of stations by using the same independent variable as in the seven-parameter equations in computing regression equations for the 164 stations. The shorter-record crest-stage stations with larger time-sampling errors were deleted from the 164 station equations, which probably contributed to the lower standard error.

The seven-parameter alternative equations are more difficult to apply than the equations in Table 1 because the variable LT is not easily determined and requires access to both rainfall and runoff hydrograph data applicable to the basin. The alternative equations have not been reproduced for this paper but are available in the report by Sauer, Thomas, Stricker, and Wilson (1).

Limitations of Significant Variables

The effective or usable range of basin and climatic variables to be used in the estimating equations described in this paper is given below:

Variable	Min	Max
A ($miles^2$)	0.2	100
SL (ft/mile)	3.0	70
RI2 (in)	0.2	2.8
ST (%)	0	11
BDF	0	12
IA (%)	3.0	50
LT (h)	0.2	45

If values outside these ranges are used, the standard error may be considerably higher than for sites where all variables are within the specified range. The maximum value of SL for use in the equations is 70 ft/mile, although numerous watersheds used in this study had SL values up to 500 ft/mile.

Effects of Detention Storage

If temporary in-channel storage, or detention storage, is significant, it will tend to reduce peak discharges. The estimating equations defined by this study were calibrated without including those stations known to be affected by temporary detention storage and therefore represent conditions relatively free of the effects of detention storage. The recommended way to determine the effect of detention storage in a specific watershed is through the use of reservoir and channel routing techniques, which is beyond the scope of this study.

ACKNOWLEDGMENT

This paper was prepared as part of a research project started in 1978 to study the effects of urbanization on the magnitude and frequency of peak discharges. We wish to acknowledge the financial support of FHWA and the leadership and guidance of Roy Trent of FHWA in initiating the project. Special assistance from Walter J. Rawles, Science and Education Administration, U.S. Department of Agriculture, is also acknowledged. He acquired and provided to the Geological Survey a large part of the data base, specifically land use and soils data, and collaborated with the Geological Survey in compiling and publishing the literature review. Finally, special acknowledgment is given to the many Geological Survey personnel in district offices throughout the nation who assisted in compiling the gaging station data used in this study.

A copy of the complete data base for the study can be obtained by writing to Chief, Data Management Section, U.S. Geological Survey, Mail Stop 437, National Center, Reston, Virginia 22092.

REFERENCES

1. V.B. Sauer, W.O. Thomas, Jr., V.A. Stricker, and K.V. Wilson. Flood Characteristics of Urban Watersheds in the United States: Techniques for Estimating Magnitude and Frequency of Urban Floods. FHWA, Rept. FHWA-RD-81-178, 1981.
2. W.J. Rawls, V.A. Stricker, and K.V. Wilson. Review and Evaluation of Urban Floodflow Frequency Procedures. U.S. Department of Agriculture, Bibliographies and Literature of Agriculture 9, 1980, 62 pp.
3. Guidelines for Determining Floodflow Frequency. Water Resources Council, Washington, DC, Bull. 17A, 1977.

Publication of this paper sponsored by Committee on Hydrology, Hydraulics, and Water Quality.

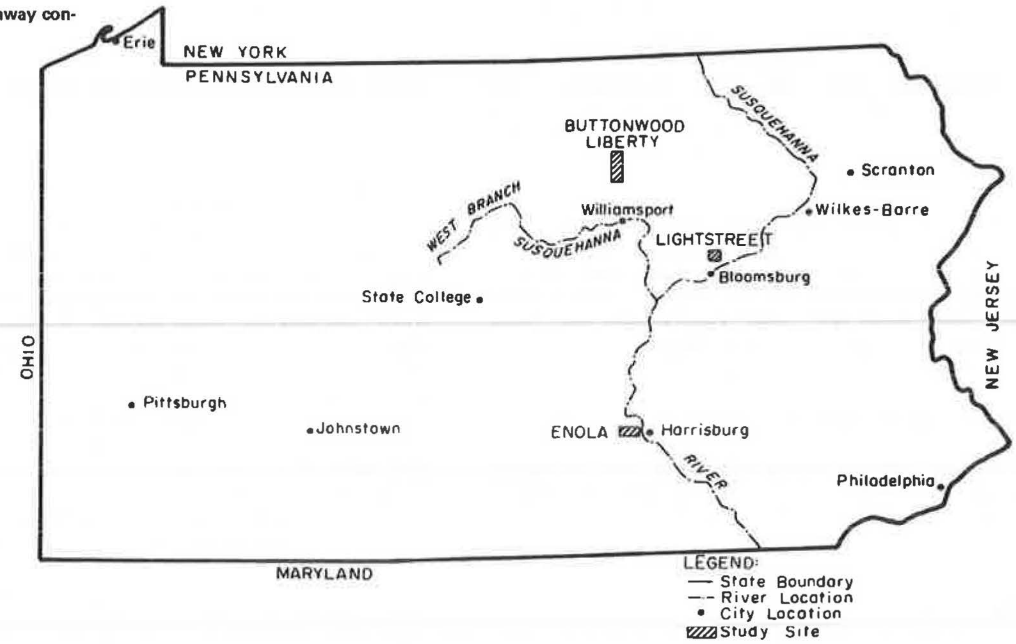
Comparison of Prediction Methods for Soil Erosion from Highway Construction Sites

ARTHUR C. MILLER, WILLIAM J. VEON, AND RONALD A. CHADDERTON

The disturbance of land by construction is almost invariably accompanied by sudden, sometimes drastic increases in the potential for soil erosion. The amount of sediment eroded and delivered to a stream should be minimized within practical economic limits. Prediction methods for soil erosion from highway construction sites are compared. All but one of the methods, a new rational method, are currently being used to predict soil erosion. The accuracy of the methods varied from 55 to 85 percent based on a mean error analysis. The best predictive method determined from the data analyzed was a new rational method.

The disturbance of land by construction is almost always accompanied by sudden, sometimes drastic increases in soil erosion. Erosion controls should be selected through a process of comparing the costs of controls at each site with the environmental, economic, and other benefits or forgone damages to be obtained in the local region. The first step in such a process, of course, should be the prediction of quantities of material to be eroded.

Figure 1. Location of highway construction sites.



Engineers must be able to predict the potential amount of sediment eroded from construction sites before they can intelligently design and implement erosion control measures. The intent of this paper is to critique and evaluate some of the sediment erosion prediction methods currently in use.

PREDICTING SOIL EROSION

There are four levels of sophistication that can be used to determine sediment yield:

1. Level 1 relations are prediction equations developed from regression analysis with average parametric values for input variables. The rational formula for determining runoff is such an equation, and the universal soil loss equation (USLE) for predicting sediment yield, developed by Wischmeier and Smith (1), is another.
2. Level 2 relations are similar to those in level 1, but the methods combine potential erosion with a routing procedure (delivery ratio) to predict the amount of sediment entering the stream system. The delivery ratios are typically developed by using regression analysis with measured data. An example of level 2 would be the Younkin equation presented in a later section of this paper.
3. Level 3 relations incorporate the unit hydrograph theory in hydrology and are appropriately called unit-sediment-graph (USG) methods. Many of the assumptions in the derivation of the unit hydrograph apply to the USG. The advantage of the USG is that it can be used in water-quality modeling where concentration of sediment is a significant indicator of pollution.
4. Level 4 uses a combination of equations to solve the dynamic soil erosion process. Many causal factors affect soil erosion. A particle is first detached from the surrounding soil by the impact of the rainfall energy or by the erosive properties of the overland flow. Once the soil particle has been detached, it is transported over the construction site by rainfall-runoff. The sediment is finally delivered to the stream system, where it may or may not pose an ecological problem. The methods that constitute level 4 all attempt to model analytically each of the important steps in the erosion process. Methods developed by Meyer and Wischmeier (2) and Simons and Li (3) are good examples of this modeling.

This paper concentrates only on the level 2 relations. The relations of level 1 are too simple to predict soil loss accurately; there are currently few or no data available to calibrate the prediction equations of levels 3 and 4 adequately, even though with combined research these procedures will be more usable in the near future and will be inherently superior to the level 2 relations described here for reasons in addition to their dimensional consistency.

ANALYSIS OF EXISTING PREDICTIVE METHODS

This analysis involves six existing relations for estimating construction sediment yield and one relation developed specifically for this study. The various equation terms and methods of determination are defined only once as each is first introduced in the analysis. Although the existing equation factors and coefficients were supposedly fixed by their original authors, modifications were made in some cases to achieve better results. When modifications were necessary, 80 percent of the total data was used in the calibration process, which left 20 percent of the data for testing and calculating the resulting relation.

SITE DESCRIPTIONS

The U.S. Geological Survey, in cooperation with the Pennsylvania Department of Transportation (DOT), has collected rainfall, stream-flow, suspended sediment, and turbidity data at several Pennsylvania sites downstream from highway construction (see Figure 1). One site, located near Enola in Cumberland County, consisted of five small adjacent drainage basins. Another site, located near Lightstreet in Columbia County, consisted of two subareas. The third site, located in the Buttonwood-Liberty area of Lycoming and Tioga Counties, consisted of four subbasins. All drainage areas were gaged for a minimum of 2.5 continuous years. Figure 1 shows the locations of the sites and their proximities to the larger urban centers of the state (4).

Table 1. Comparison of error parameters and equation significance terms for seven equations considered.

Equation		Error				Significance	
No.	Name	Avg Error (%)	95 Percent-of-Data Avg Error (%)	Median Error (%)	Portion of Estimate in Error by at Least 100 Percent (%)	R^2	F/F*
1a	Younkin	510	219	83	33	0.45	51.6/3.00
2a	Scott Run	499	166	91	35	-	-
3a	USLE 1	638	132	73	29	0.61	220/3.84
4a	USLE 2	500	193	76	28	0.002	0.27/3.92
5b	USLE 3	282	98	68	25	0.37	33.2/3.07
6	USLE 4	282	98	68	25	0.37	33.2/3.07
7	Rational model	119	74	55	22	0.84	156/2.45

DATA DESCRIPTION

The U.S. Geological Survey provided basic precipitation, stream-flow, sediment, and turbidity data for the various study areas. The precipitation information was obtained in the form of cumulative rainfall amount versus time plots as recorded by graphic analog rain gages. The stream-flow data were obtained in the form of water stage versus time plots as recorded by continuous strip-chart recorders. Pertinent stream-flow rating curves were also available so that the water stage values could be transformed into discharge values. Finally, plots of suspended sediment concentration versus time were obtained. The Geological Survey used automatic pendulum samplers to collect the sediment samples during storms. Samples were taken at predetermined time increments, usually every 15 min, and later they were analyzed to determine the sediment concentrations. Between storms, suspended sediment samples were collected intermittently by hand with U.S. DH-48 samplers. In addition to the hydrologic data, detailed construction data were incorporated into the data base.

DATA MANAGEMENT

Hydrologic data for about 25 years for the seven study areas (for both control and construction periods) were processed by the personnel of the Pennsylvania State University Hydrology Laboratory. The initial step in collapsing the data to usable form was isolating the "good" storm events. (A storm was defined, for this study, as the occurrence of at least 0.10 in of rainfall with a separation time of at least 5 h from any other rainfall event.) The events were then ranked according to the quality of the respective suspended sediment graphs, and only data that were considered consistent were used in the analysis (5).

All of the data were reduced and put on magnetic tape. The digitized information was then transferred to four sets, one each for precipitation, stream-flow, sediment, and construction information for each rainfall event.

EQUATIONS

Younkin

Younkin (6) developed the following equation to predict the suspended sediment loads in streams caused specifically by uncontrolled, rainfall-induced erosion from highway construction sites in Pennsylvania:

$$SY_T = [Cy\, R_S(\log A_C)^{2.80}(1.93)^D]/(P_L)^{0.66} \qquad (1)$$

where

SY_T = total sediment yield (tons),
Cy = equation constant with a value between 0.129 and 0.153 for the watersheds Younkin studied,
R_S = rainfall-erosion index on a per storm basis,
A_C = area under highway construction (acres),
D = average depth of highway cut and fill (yd), and
P_L = proximity factor.

Cy reflected the overland transport factors of slope gradient and natural gradient and natural ground cover as well as the erodibility of the basin soils. D was used to express the slope length and gradient of the exposed construction area. R_S, the rainfall factor, and A_C, the exposed-area term, were taken to be measures of the soil detachment phase of soil erosion. Finally, P_L represented the overland transport phase of the erosion process. It was defined as the ratio of the surface area between the upslope side of the construction area and the nearest stream to the total area exposed by construction up to the time of the storm in question.

For this study, Younkin's equation was modified by using regression analysis on the data base previously described. The parameters that Younkin originally defined were not changed, but the coefficients were calibrated to the new data. The resulting equation was as follows:

$$SY_T = 0.127(R_S)^{1.26}(\log A_C)^{1.27}(1.19)^D(P_L)^{1.90} \qquad (1a)$$

Equation 1a, though admittedly much different, was found to be statistically better than Equation 1 and was used in the comparisons presented in Table 1.

Scott Run

Guy, Vice, and Ferguson (7) studied the effects of highway construction on the sediment load carried by Scott Run in Fairfax, Virginia. After continued analysis, they concluded that the most accurate relation between causal factors and measured suspended sediment discharge was

$$SY_T = Q_{ST}T_R A_C K_S \qquad (2)$$

where

SY_T = suspended sediment discharge or sediment yield (tons),
Q_{ST} = mean storm-event sediment transport rate (tons/day/acre of highway construction),
T_R = duration of storm runoff (days), and
K_S = mean seasonal erodibility factor.

Equation 2 was recalibrated by using the new data base and the resulting equation became

$$SY_T = 0.17\, Q_{ST}T_R A_C K_S^{0.74} \qquad (2a)$$

Modified USLE 1

A representative version of Williams' modified USLE (8), assumed to have applicability to highway and other types of construction sites, was taken in this study to be

$$SY_T = a(Q \times q_p)^b \, \overline{K}_C \overline{LS}_C \quad (3)$$

where

- a,b = coefficients with values of 95 and 0.56, respectively, in Williams' study;
- Q = volume of direct runoff (acre-ft);
- q_p = peak flow rate (ft^3/s);
- $\overline{K}_C$ = average soil erodibility factor for the construction site at the time of the storm (tons/acre/unit of erosion index); and
- $\overline{LS}_C$ = average slope length factor and slope gradient factor for the construction site at the time of the storm (L is the ratio of soil loss from a specific field slope length to that from a 72.6-ft length for the same soil type and percentage slope, and S is the ratio of soil loss from a specific field gradient to that from a 9 percent slope).

Equation 3 was calibrated for the data. The a and b coefficients were evaluated by a simple least-squares regression analysis that related the dependent variable ($SY_T/\overline{K}_C\overline{LS}_C$) to the independent variable (Qxq_p). A log-log transformation to linearize the model was necessary prior to the application of the regression routine. The modified equation became

$$SY_T = 0.10(Q \times q_p)^{0.68} \overline{K}_C \overline{LS}_C \quad (3a)$$

Note that the a coefficient was calibrated to be 0.10 versus Williams' reported coefficient of 95. The reason for this difference is the site dependency of regression equations. However, the b coefficient does offset the a value, and the difference is not as significant as it might appear.

Modified USLE 2

Holberger and Truett (9) adapted the USLE to the estimation of sediment yields from construction sites. To do this, they empirically fitted factors to the equation to account for the effects of intervening terrain between the construction area and the point of sediment measurement in a nearby watercourse. One factor was the average distance from the foot of the exposed area to the nearest perennial system, and the other parameter was the percentage of the drainage basin undergoing construction. The Holberger and Truett equation took the following form:

$$SY_T = R_S \overline{K}_C (\overline{L}_C)^d (\overline{S}_C)^e (Do)^f \quad (4)$$

where d, e, and f are constants and Do is a factor, considered to be a sediment "loading function" or delivery ratio term, that accounts for the effects of intervening terrain between the construction area and the point of interest in a nearby receptor stream. Equation 4 was calibrated for the data to be

$$SY_T = 0.10 R_S \overline{K}_C \overline{LS}_C (Do)^{-0.13} \quad (4a)$$

Values of d and e = 1 and f = 0.13, plus a coefficient of 0.10, were needed.

Modified USLE 3

The USLE 3 and USLE 4 relations are both gross erosion-delivery ratio equations. USLE 3, the U.S. Soil Conservation Service version of the original USLE applicable to construction areas, is defined as

$$A = R \overline{K}_C \overline{LS}_C \quad (5)$$

where A is the average annual soil loss in tons per acre per year and all other parameters are evaluated on an annual basis. However, in this study the USLE parameters were analyzed on a per storm basis in the form

$$A_S = R_S \overline{K}_C \overline{LS}_C \quad (5a)$$

and the corresponding estimated construction sediment yield values for each storm were computed from the following equation:

$$SY_T = A_S \times DR \quad (5b)$$

where DR is the delivery ratio based on the USLE equation.

Modified USLE 4

Clyde and others (10) substituted an erosion control factor (VM) for the crop and management factors in the original USLE so that they could estimate soil loss from highway construction sites. The VM term described the effects of all erosion control measures that could be implemented for the soil surface as well as chemical treatments. The parameter did not, however, encompass the effects of structures such as berms, ditches, or ponds. The equation was of the following form:

$$A_S = R_S \overline{K}_C \overline{LS}_C (VM) \quad (6)$$

A relation between the computed delivery ratios and appropriate causal factors was needed to define the DR term in Equation 5b. Only factors related to the construction site were considered. Therefore, the hydrologic and physical parameters analyzed with respect to prediction of delivery ratios for the construction sites were total direct runoff; runoff duration; maximum 30-min rainfall intensity; seasonal relative rainfall factor; effective precipitation factor; peak flow rate; Williams' direct runoff peak flow rate term (Qxq_p); average stream flow; total construction area, cleared and grubbed area; area devoted to earth-moving activities; area devoted to final grading; total exposed construction area; percentage of area devoted to different construction activities; average depth of cut and fill; total overland flow area outside of, but directly draining from, the construction site; average slope of overland flow area; average overland flow distance between the construction site and the receiving stream; and month of occurrence of the event.

The various parameters were logarithmically transformed so that a linear relation could be obtained via multiple linear regression analysis. The most suitable combination of independent causal variables with respect to the dependent delivery ratio was given by

$$DR_3 = 42.8(Q \times q)^{0.41}/(Ao)^{1.13} \quad (6a)$$

where Ao is the off-site overland flow area in acres.

Rational Model

A rational model was constructed in the form of a gross-erosion/delivery-ratio relation. The gross-erosion part of the equation provided a measure of the expected total soil detachment and erosion within the highway construction right-of-way with reference to the toe of the cut and/or fill slopes. The delivery part of the equation provided a measure of the portion of the total erosion actually transported to the stream. The proposed equation took the following form:

$$SY_T = [a(\bar{K}_C)(\bar{S}_C^1)(A_E)^b(M)^c(P)^d(U)^e] / [(\bar{L}_C^1)(V)] \tag{7}$$

where a, b, c, d, and e are constants and

M = rainfall parameter,
P = seasonal parameter,
U = runoff parameter, and
V = proximity parameter.

The soil erodibility term $(\bar{K}_C)$, average percentage slope $(\bar{S}_C^1)$, and slope $(\bar{L}_C^1)$ of the construction area and the proximity parameter were not fitted with coefficients because each of these factors had only three different values since the data were collected on only three distinct construction sites.

The data variation for these variables was not considered to be significant. However, the terms themselves were considered to be important and necessary in any sediment yield prediction equation and were thus incorporated into the dependent variable parameter of the proposed least-squares multiple regression relation.

The various factors composing Equation 7 were chosen to represent specific effects in the soil erosion process. The rainfall parameter is a measure of the power of a storm to detach soil particles. The $\bar{K}_C$ parameter is a measure of the susceptibility of a soil to detachment and erosion. The $(\bar{S}^1/\bar{L}^1)$ ratio (topographic factor) is assumed to be a measure of the susceptibility of the reshaped highway right-of-way slopes to erosion in addition to being a measure of the sediment transport capabilities. The exposed construction area is a measure of the maximum possible erosion. The seasonal factor is a measure of the general variation to be expected in meteorological conditions, the seasonal variation in soil moisture, and the seasonal variation in available runoff. The runoff factor is a measure of the transport capabilities of the storm runoff. Finally, the proximity factor is assumed to be a measure of the effects of the intervening terrain between the construction site and the point of sediment measurement.

All of the parameters considered in Equation 7 are rational indicators of the various components of the soil erosion/sediment delivery process. The actual proportionalities of the factors with respect to sediment yield, as indicated in the equation, are also rational from the standpoint of expected tendencies. That is, higher soil erodibility values, steeper slope gradients, greater quantities of rainfall and runoff in the form of larger values of the rainfall and runoff factors, and larger exposed areas should all tend to be associated with greater quantities of soil erosion and sediment yield. By definition and actual derivation, higher soil erodibility values are synonymous with those soils that are more susceptible to erosion. Steeper slope gradients will act to accelerate the flow of runoff water more than flatter slope gradients; and thus, besides detachment of soil by raindrop impact, the faster-flowing waters will detach or erode additional soil particles. Greater quantities of rainfall and runoff will potentially provide for greater detachment and transport of soil particles. Finally, larger areas of exposed soil should naturally tend to allow for larger quantities of sediment yield.

On the other hand, larger slope lengths should be associated with smaller quantities of soil erosion and sediment yield. The larger the slope length, given the same quantity of runoff and the same slope gradient, the greater should be the potential for deposition due mainly to the loss of energy (friction loss) as the runoff water flows down the slope. Loss of energy due to friction or turbulence or any other means can be translated directly into less energy available for keeping soil particles in suspension and, consequently, a greater chance for deposition.

The proportionality of the proximity factor with respect to sediment yield will vary depending on which of the possible proximity terms is considered. The total overland flow area outside of, but directly draining, the construction site (Ao) and the average overland flow distance between the construction site and the receiving stream (Do) should be expected to be inversely proportional to sediment yield. That is, larger values of Ao and Do should be associated with smaller quantities of sediment yield for the same reason as given above for slope length. However, the average slope of the off-site overland flow area (So) should be expected to be directly proportional to sediment yield in that steeper slopes should allow a larger portion of the total suspended sediment to reach the stream, all other conditions being the same. The purpose of the seasonal factor in Equation 7 is to act as an adjustment variable (i.e., the parameter is used as a fitting coefficient) to account for a portion of the variation in the measured sediment yield data that the combination of the other factors could not otherwise account for. Thus, its relation to sediment yield, whether it be directly or inversely proportional, should be solely dictated by the way in which the factor can best reduce the remaining variability in the data once the other variables in the equation are considered.

Values for the Equation 7 coefficients (a, b, c, d, and e) were determined by a least-squares multiple regression analysis. As indicated previously, the $\bar{K}_C$, $\bar{S}_C^1$, $\bar{L}_C^1$, and V factors were incorporated into the dependent variable, which took the following form (prior to logarithmic transformation):

$$DV = [(SY_T)(\bar{L}_C^1)(V)] / [(\bar{K}_C)(\bar{S}_C^1)] \tag{8}$$

with the V variable represented by Ao or Do. The V variable was transferred to the denominator of Equation 8 when it was represented by the So factor. The independent variables were, then, the logarithmically transformed versions of the A_E, M, P, and U parameters.

DISCUSSION OF RESULTS

As anticipated, the rational model proved to be the best or most consistent estimator of sediment yield at highway construction sites. The six existing techniques for estimating sediment yield were generally found to be less adaptable to the available data. This was most likely due to the necessary use of average values in defining the physical parameters associated with the construction sites. Even though each of the six existing equations was recalibrated to allow the equation coefficients to adjust to the use of the maximum average values, the results were, overall, less than impressive.

As mentioned previously, the rational model was composed of a combination of factors that represented the effects of various physical properties and hydrologic phenomena with regard to the soil erosion process and that together seemed to explain the process most reasonably. Each of the other six existing equations was deficient in one or more of the parameters considered to be important. The Younkin equation was composed of a rainfall factor, an affected-area term, a slope parameter, and a proximity factor but was missing a runoff term, a soil erodibility parameter, a slope length factor, and a seasonal term when compared with Equation 7. The Younkin Cy coefficient was reported to reflect the overland transport factors of slope gradient and natural cover as well as the erodibility of the basin soils; however, it could also be interpreted to reflect the overland transport terms of the slope gradient and natural ground cover. The Younkin equation is still deficient in three parameters that are believed to be significant in explaining the soil erosion process.

The Scott Run equation (Equation 2) was composed of a runoff parameter, a time duration factor, an affected-area term, and a seasonal factor but was deficient in a rainfall parameter, a slope gradient term, a slope length factor, a proximity term, and a soil erodibility parameter. Although the Scott Run seasonal factor was reported to be a seasonal erodibility term, it really is not in the strictest sense but is a factor that more heavily weighted those times during the year when larger than average quantities of sediment were measured.

The modified USLE 1 (Equation 3) was composed of a runoff factor, a soil erodibility term, and a slope-gradient/slope-length parameter. The relation was missing a rainfall factor, an affected-area term, a seasonal parameter, and a proximity term. Although the runoff factor was reported to have adequately replaced both the rainfall parameters and the need for a delivery ratio sediment yield via the original USLE, it is considered to be incomplete in totally representing the hydrologic aspects of the detachment and transport process. The runoff term should be interpreted as being representative of the major portion of the transport phase and the runoff or scour portion of the detachment phase but not also representative of the rainfall impact portion of the detachment and transport phases. The impact of raindrops on the soil surface loosens the upper soil particles, making them susceptible to easier entrainment by runoff waters at the beginning of the storm. Since the soil particles are already loosened, less runoff energy is needed for scour and more is available for transport. Once runoff is fully established in the form of sheet flow, the raindrop impact energy is no longer totally expended in loosening soil particles, but some (or all) is imparted onto the sheet flow, depending on depth of flow and momentum of raindrops, which increases the available energy for transport and for scour. Thus, it seemed appropriate to consider a separate rainfall term that solely represented the rainfall energy.

The modified USLE 2 (Equation 4) was composed of a rainfall factor, a soil erodibility term, a slope gradient parameter, a slope length factor, a proximity term, and, indirectly, an affected-area parameter but was deficient in a runoff factor and a seasonal term when compared with Equation 7. The runoff factor was found to be the most significant of all predictor terms, and so exclusion of the parameter should and did lead to less-than-acceptable results.

USLE 3 and USLE 4 (Equations 5 and 6) were both composed of a rainfall factor, a runoff parameter, a soil erodibility term, a slope gradient factor, a slope length parameter, a proximity factor, and, indirectly, an affected-area term. USLE 4, in addition, had an erosion control factor that could not be evaluated in this study but could become a significant factor in future research, reflecting highway right-of-way soil surface condition. Therefore, only the seasonal parameter was missing from either of the equations when they were compared with Equation 7. Although the seasonal factor was the least significant of the force-fit model terms, its purpose was to act as an adjustment parameter in "fine-tuning" the equation. Thus, its exclusion, although not an overly serious omission, was reflected in the predictive power of the equation.

The rational model equation (Equation 7) not only was considered to be the most complete and rational of the equations analyzed but also proved to be the best relation to use in estimating measured construction sediment yield. Table 1 gives the various error parameters and significance data for each of the seven equations analyzed. The superiority of Equation 7 can be clearly established in Table 1 if comparison is made among the error parameters and the R^2 values. Only in the F/F* category did the force-fit model not provide the most significant values. Nevertheless, the F and F* values indicated that the relation was highly significant at the 95 percent confidence level.

CONCLUSIONS

Six existing equations used by engineers to predict soil loss from highway construction sites were compared with a seventh method developed with data gathered from three highway construction sites in Pennsylvania. The accuracy of all the equations is best illustrated in Table 1 by the average error prediction (column 1). The smallest average error is 119 percent and the largest is more than 600 percent. How good or bad are these errors? It really depends on how the result is intended to be used. There is nothing really wrong with the accuracy of these equations as long as the user is aware of the possible errors and the limits of the methods. In time, as additional data are gathered, level 3 and level 4 equations will become verified and it is hoped that they will eventually be implemented in most design situations.

REFERENCES

1. W.H. Wischmeier and D.D. Smith. Predicting Rainfall-Erosion Losses: A Guide to Conservation Planning. U.S. Department of Agriculture, Agriculture Handbook 537, 1978.
2. L.D. Meyer and W.H. Wischmeier. Mathematical Simulation of the Process of Soil Erosion by Water. Trans., American Society of Agricultural Engineers, Vol. 12, 1969, pp. 754-762.
3. D.B. Simons and R. Li. Analysis of Watersheds and River Systems. Colorado State Univ., Fort Collins, CO, Continuing Education Short Course Notes, Summer 1979.
4. A.C. Miller, E.L. White, and W. Veon. A Procedure to Predict Sediment Flow from Highway Construction Sites: Volume II--Data Report. FHWA, Rept. FHWA-PA-81-002, 1980.
5. A.C. Miller, E.L. White, and W. Veon. A Procedure to Predict Sediment Flow from Highway Construction Sites: Volume I--Design Procedures. FHWA, Rept. FHWA-PA-81-001, 1980.
6. L.M. Younkin. Prediction of the Increase in Suspended Sediment Transport Due to Highway Construction. Pennsylvania Department of Transportation, Harrisburg, Res. Project 08-39140, Interim Rept., 1974.
7. H.P. Guy, R.B. Vice, and G.E. Ferguson. Sediment Movement in an Area of Suburban Highway Construction. U.S. Geological Survey, Water-Supply Paper 1591-E, 1969.
8. J.R. Williams. A Sediment Graph Model Based on

an Instantaneous Unit Sediment Graph. Water Resources Research, Vol. 14, No. 4, 1978.
9. R.L. Holberger and J.B. Truett. Sediment Yield from Construction Sites. Proc., 3rd Federal Inter-Agency Sedimentation Conference, Denver, CO, 1976.
10. C.G. Clyde and others. Manual of Erosion Control Principles and Practices. Utah Water Research Laboratory, Utah State Univ., Logan, Hydraulics and Hydrology Series, UWRL-H-78-02, June 1978.

Publication of this paper sponsored by Committee on Hydrology, Hydraulics, and Water Quality.

Drainage Control Through Vegetation and Soil Management

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A procedure is developed that promotes the use of soil infiltration capacity and available soil profile storage in the design of highway drainage systems. By considering a design volume represented by the soil profile storage, the dependence on constructed runoff detention basins or other drainage structures can be reduced. This design volume is selected as the antecedent available storage in the soil that produces the T-year runoff from the T-year design rainfall. Data requirements of the overall methodology are commonly available soils, vegetation, and climatic parameters. The influence of antecedent moisture on the relation between rainfall and runoff frequency was tested by using 5 years of daily soil moisture and hourly rainfall and 10 years of hourly runoff data from the Calhoun Experimental Forest near Union, South Carolina. Equations that estimate the design antecedent moisture and its associated storage for ungaged sites are developed. Vegetation and soil management techniques that increase the volume of soil profile storage and soil infiltration capacity are reviewed. In addition, the Calhoun soil moisture data are fitted to frequency distributions to assess the risk involved in using soils-based drainage designs.

Traditional drainage design is usually based on (a) an estimate of peak design storm runoff for a given area and (b) man-made facilities that can accommodate and transport these peak flows away from developed sites. In recent years, however, the trend has shifted toward using on-site or source control to reduce flow rates leaving developed areas and thus prevent increased risk of downstream flooding. This change in philosophy has resulted in part from the excessive cost of building detention facilities but mostly from the growing concern over the effects of storm runoff downstream.

Engineers who design urban drainage systems often choose to use paved, open drainage channels and curb and gutter because of their high efficiency and stability in transporting runoff. Unfortunately, the efficiency that makes paved channels and curb and gutter desirable for removing runoff can cause detrimental effects downstream, including increased potential for flooding, erosion of natural waterways, and sediment pollution. Consequently, grassed roadside ditches or swales, infiltration pits and trenches, and porous pavements have been suggested for use in urban drainage design. All of these facilities rely on the use of soil infiltration capacity and soil profile storage to reduce the volume of storm runoff. This paper concentrates on the development of a methodology that allows the water storage capabilities of the soil profile to be explicitly included in the design of on-site drainage systems for handling storm water.

RAINFALL FREQUENCY VERSUS RUNOFF FREQUENCY

In the design of facilities for managing storm water, it is common practice to assume that the peak discharge from some selected design storm has the same return period as the rainfall depth in some "critical" duration. However, numerous studies of watersheds have concluded that the return frequency of runoff produced by a given storm is not fixed but varies over a wide range and depends on antecedent conditions in the catchment (1).

The runoff response on natural watersheds is highly sensitive to antecedent soil moisture or surrogate measures of wetness, such as five-day antecedent precipitation. This means that the proper selection of antecedent moisture is necessary to produce the desired T-year design runoff from the T-year rainfall. In a study of the density function of the difference between gross rainfall and the antecedent soil moisture deficit, Beran and Sutcliffe (2) concluded that for a given location and season the mean soil moisture deficit produces the rainfall excess of T-year return period from the rainfall of the same return period.

In critiquing a paper by Larson and Reich (3), Laurenson addressed the question, When the design storm-loss-rate unit hydrograph method of flood estimation is being used, what loss rate should be selected to produce equality of rainfall and runoff recurrence interval? He suggested that the correct value is the median of all values of loss rate that have been derived for the catchment.

CURRENT DESIGN PROCEDURE

Current drainage design practices can be summarized as follows:

1. Postdevelopment site conditions, such as slope, vegetation, and replacement of disturbed soils, are planned and minor attention is given to hydrologic impacts.
2. The runoff hydrograph or peak flow produced by some design rainfall of return frequency T_r is calculated. Antecedent soil moisture conditions are arbitrarily set, maybe at saturation, to yield a conservative runoff hydrograph of peak-flow estimate.
3. If no runoff restriction is in force, then outlet pipes from the site are sized to carry the predicted peak flow (Q_p). If restrictions are in force and they are exceeded by Q_p, then a detention structure with a controlled outlet must be sized so that Q_{max} allowed by the restrictions is not exceeded.