CALCULATING SEDIMENT DISCHARGE FROM A HIGHWAY CONSTRUCTION SITE IN CENTRAL PENNSYLVANIA

By Lloyd A. Reed, Janice R. Ward, and Kim L. Wetzel

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Multiply inch-pound units	By	To obtain SI units
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
acre	0.4047	hectares (ha)
ton (short)	0.9072	metric ton (t)
square mile (mi^2)	2.590	square kilometer (km^2)
ton per square mile (ton/mi^2)	2.242	megagram per hectare (Mg/hectare)

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ABSTRACT

The Pennsylvania Department of Transportation, the Federal Highway Adminstration, and the U.S. Geological Survey have cooperated in a study to evaluate two methods of predicting sediment yields during highway construction. Sediment yields were calculated using the Universal Soil Loss and the Younkin Sediment Prediction Equations. Results were compared to the actual measured values, and standard errors and coefficients of correlation were calculated.

Sediment discharge from the construction area was determined for storms that occurred during construction of Interstate 81 in a 0.38-square mile basin near Harrisburg, Pennsylvania. Precipitation data tabulated included total rainfall, maximum 30-minute rainfall, kinetic energy, and the erosive index of the precipitation. Highway construction data tabulated included the area disturbed by clearing and grubbing, the area in cuts and fills, the average depths of cuts and fills, the area seeded and mulched, and the area paved.

Using the Universal Soil Loss Equation, sediment discharge from the construction area was calculated for storms. The standard error of estimate was 0.40 (about 105 percent), and the coefficient of correlation was 0.79. Sediment discharge from the construction area was also calculated using the Younkin Equation. The standard error of estimate of 0.42 (about 110 percent), and the coefficient of correlation of 0.77 are comparable to those from the Universal Soil Loss Equation.

INTRODUCTION

The Pennsylvania Department of Transportation, the Federal Highway Adminstration, and the U.S. Geological Survey have cooperated in a study to evaluate two methods of predicting sediment yields during highway construction. The Pennsylvania Department of Transportation uses two methods to compute the quantity of sediment discharged from an area of highway construction: the Universal Soil Loss Equation and the Younkin Sediment Prediction Equation. The purpose of this study was to compare the accuracy of the two methods using sediment discharge data collected from January 1973 to September 1974 below an area of highway construction near Harrisburg, Pa. Sediment yields, calculated using the two equations, were compared to the actual measured values, and standard errors of estimate and coefficients of correlation were calculated.

The contents of this report reflect the findings of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Pennsylvania Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

STUDY AREA

The study area is in the Conodoguinet Creek basin in Cumberland County, just west of Harrisburg (fig. 1). Rainfall, streamflow, and suspended-sediment data were collected from two small basins formed by Conodoguinet Creek tributaries 1 and 3. Tributary 1, used as a control, drains an area of 0.77 mi^2 that was unaffected by highway construction. Tributary 3 drains an area of 0.38 mi^2, of which about 25 acres (0.04 mi^2) were affected by construction of Interstate 81. Figure 2 shows a part of basin 3 during highway construction.

The two drainage basins extend from the crest of Blue Mountain to the stream-gaging stations at Valley Street for basin 3 and near State Route 944 for basin 1. The altitude of Blue Mountain is about 1,200 ft, and altitudes of the stream-gaging sites were about 400 ft. Slopes on Blue Mountain average about 30 percent, but some are as high as 50 percent. Slopes average about 4 percent in most of the valley.

Blue Mountain is underlain by shale, sandstone, and quartzitic sandstone; the valley is underlain by shale. Soils on Blue Mountain are classified as very stony and gravelly loams. The valley soils, derived from the underlying Martinsburg Formation, are mostly shaly, silt loams and range from 1 to 5 ft thick, though most are 2 to 3 ft thick. The topsoil is generally 44 percent sand, 41 percent silt, and 15 percent clay. The subsoil is generally 39 percent sand, 35 percent silt, and 26 percent clay. The mountainous area and the steeper parts of the valley are forested. The flatter areas in the valley are open fields, a few of which are actively farmed; the rest is grassland. Residential development is light. Highway construction in basin 3 required the clearing, grubbing, cutting, and filling of 25 acres.

DATA COLLECTION

Streamflow, suspended-sediment concentration, and rainfall data were collected at the two drainage basins indicated in figure 1 from October 1970 to September 1974. Continuous stage data were collected by recorders at the stream gages shown on figure 1. Stages in each stream were related to stream flow on the basis of periodic current-meter measurements; daily and storm discharges were calculated from the stage records. Water samples were collected with automatic samplers as frequently as every 15 minutes during storms when concentrations changed rapidly, and analyzed for suspended-sediment concentration. After the samples had been analyzed, the suspended-sediment concentrations were plotted against time. From the suspended-sediment concentrations and discharge records, sediment loads were calculated for the storms. A recording rain gage was installed in each basin. Data were collected in the control basin, basin 1, from 1970 through 1974. In basin 3, preconstruction data were collected from 1970 through 1972, and construction data were collected from 1973 through 1974.

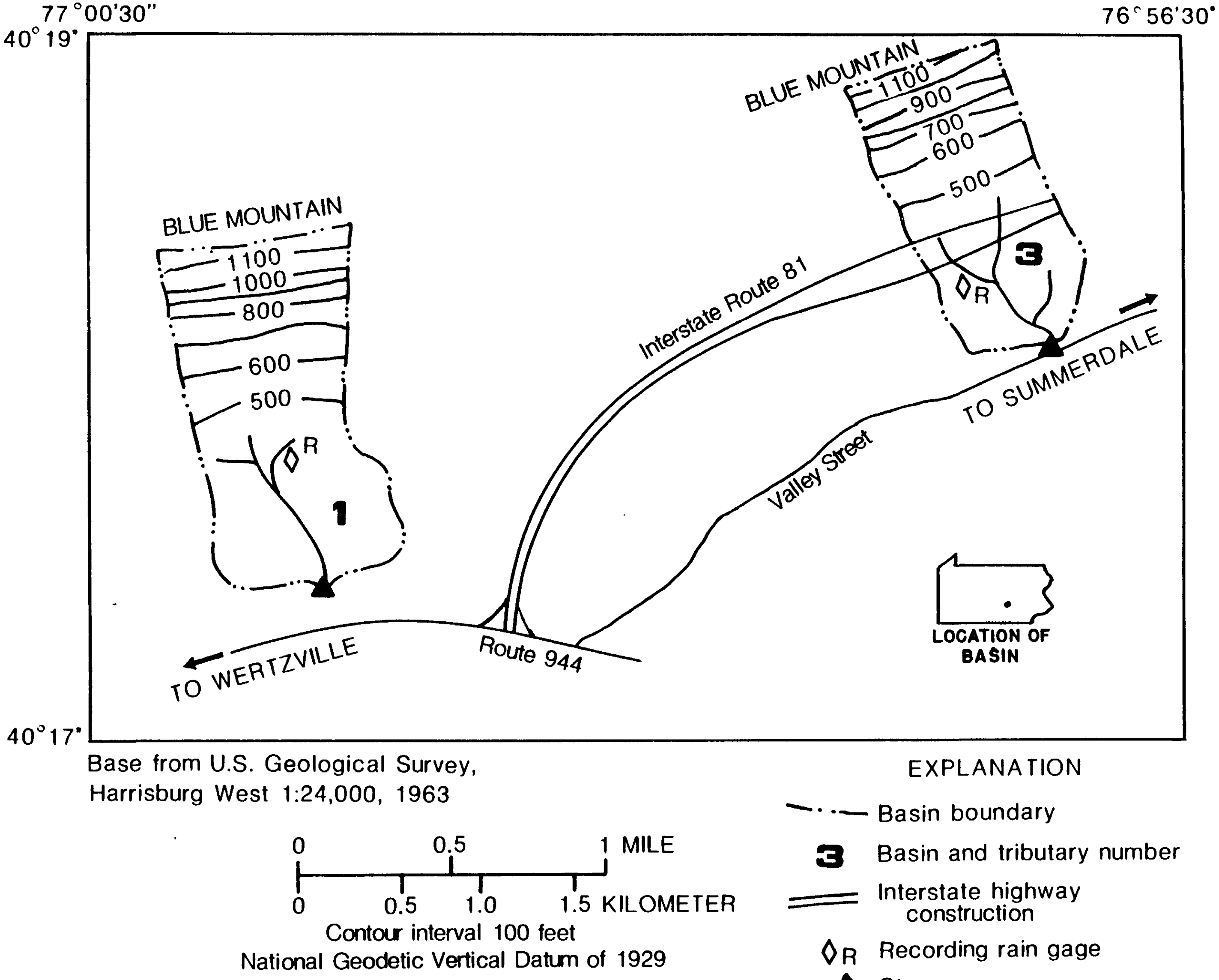

Figure 1.--Location of the basins and the data-collection sites.

Figure 2.--Area disturbed by construction in basin 3, September 20, 1973.

SEDIMENT PREDICTION EQUATIONS

The Pennsylvania Department of Transportation uses two equations to predict sediment discharge from areas affected by highway construction. The Universal Soil Loss Equation was developed to predict soil losses from cropland (Wischmeier and Smith, 1965) and is generally expressed as:

$$A = RKLSCP; \tag{1}$$

where A = soil loss per unit area (tons per acre);

R = rainfall factor, the kinetic energy of the precipitation times the maximum 30-minute intensity divided by 100 (foot-ton-inch per acre hour);

K = soil-erodibility factor;

L = slope-length factor;

S = slope-gradient factor;

C = management factor; and

P = erosion-control practice factor.

Rainfall factors (R) for individual storms are calculated from precipitation records. The soil-erodibility factor (K) is determined from tables and soil maps that are generally available. Factors for slope length and gradient, management, and erosion-control practice are determined from the construction plans.

The Younkin Sediment Prediction Equation (Younkin, 1974) was developed from data collected during construction of Interstate 80 in Union County and Route 147 in Northumberland County, in central Pennsylvania. The equation calculates the quantity of sediment from the exposed surface area not affected by sediment or erosion controls and is expressed as:

$$QS = (C2)(R)(\text{Log } A + 1.0)^{2.80}(1.93)^{D} / P^{0.66}; \quad (2)$$

where QS = Sediment discharge in tons;

C2 = Soil-erodibility factor;

R = Rainfall factor, the kinetic energy of the precipitation times the maximum 30-minute intensity divided by 100 (foot-ton-inch per acre hour);

A = Exposed surface area (acres);

D = Average depth of cuts and fills (yards), the sum of the cubic yards of embankment and excavation divided by the square yards of surface area; and

P = Proximity factor, the sum of the construction area and the area between the construction area and the stream, divided by the construction area.

DATA TABULATION

Rainfall, sediment discharge, and highway construction data were tabulated for 96 storms that occurred during highway construction in basin 3 (table 1). Rainfall values include total precipitation, maximum 30-minute precipitation, the total kinetic energy (KE), and the rainfall-erosion index (*EI*) (Wischmeier and Smith, 1965) of the storm. The *EI* factor is calculated by computing the kinetic energy of the precipitation (KE) in foot-ton per acre, and multiplying the results by the maximum 30-minute intensity in inches per hour. Units of *EI* are foot-ton-inch per acre-hour.

Sediment discharge from basin 3 for each storm in 1970-72 was compared to the sediment discharge from the control basin and a relation was developed. This relation had a standard error of 0.22 log units (about 50 percent) and a correlation coefficient of 0.94, and was used to calculate the normal sediment discharge from basin 3 for storms that occurred during construction (1973-74). The normal sediment discharge was then subtracted from the measured discharge to determine the discharge that originated from the construction area. During construction the normal sediment discharge was about 25 percent of the total, and sediment from the construction area was about 75 percent of the total.

The drainage area of each stream was determined from topographic maps and the soil types from the general soil map of Pennsylvania. An average erodibility (*K*) of the soil (Wischmeier and Smith, 1965) was calculated with soil data from the Soil Conservation Service Technical Guide, "Estimating

Table 1.--Highway construction, precipitation, and sediment data from basin 3, January 19, 1973, to September 28, 1974

Date of storm	Precipitation: Total (inches)	Precipitation: Maximum in 30-minutes (inches)	Precipitation: Kinetic energy (foot-ton/acre)	*EI* (foot-ton-inch/ acre-hour)	Sediment discharge: total from basin (tons)	Sediment discharge: from construction area (tons)	Area disturbed by highway construction: cleared and grubbed (acres)	Area disturbed: cuts and fills (acres)	Area disturbed: seeded and mulched (acres)	Area disturbed: paved (acres)	Average depths of cuts and fills (feet)	Sediment discharge from construction area calculated using: Universal Soil (tons)	Sediment discharge from construction area calculated using: Younkin (tons)
1-19-73	0.25	0.06	140	17	0.05	0.02	25	0	0	0	0.5	0.06	0.07
1-22-73	.87	.20	580	232	7.2	5.2	25	0	0	0	.5	.73	.96
1-27-73	.52	.07	307	43	1.1	.45	25	0	0	0	.5	.14	.18
1-28-73	.85	.06	428	51	3.0	.75	25	0	0	0	.5	.16	.21
2-02-73	1.22	.20	850	340	19.	11.	25	0	0	0	.5	1.1	1.4
2-08-73	.25	.03	115	7	.78	.65	25	0	0	0	.5	.02	.03
3-17-73	.21	.03	88	25	.13	.08	25	0	0	0	.5	.08	.10
3-17-73	.65	.30	476	285	6.3	4.1	25	0	0	0	.5	.89	1.2
3-25-73	.41	.09	230	41	.36	.25	22	3	0	0	.6	.18	.17
3-30-73	.21	.07	122	17	.04	.01	22	3	0	0	.6	.07	.07
3-31-73	.32	.07	184	26	.40	.18	22	3	0	0	.6	.11	.11
4-01-73	.72	.07	413	83	2.3	1.6	14	3	0	0	.6	.27	.25
4-04-73	1.10	.25	700	350	18.	8.3	14	3	0	0	.6	1.1	1.1
4-08-73	.95	.11	520	114	3.4	1.2	7	3	0	0	.6	.27	.20
4-10-73	.45	.20	333	133	1.9	1.4	7	3	0	0	.6	.32	.24
4-17-73	.15	.03	62	4	.01	.01	7	3	0	0	.6	.01	.01
4-18-73	.10	.02	48	2	.01	.01	7	3	0	0	.6	.01	.01
4-23-73	.32	.20	264	106	.17	.13	7	3	0	0	.6	.25	.19
4-25-73	.90	.15	551	165	3.5	2.4	7	3	0	0	.6	.39	.24
4-27-73	.77	.11	424	93	3.3	2.5	7	3	0	0	.6	.23	.14
5-03-73	.32	.14	190	27	.80	.50	7	3	0	0	.6	.07	.05
5-09-73	.37	.24	264	27	1.0	.73	7	3	0	0	.6	.07	.05
5-17-73	.40	.06	234	28	.05	.01	7	3	0	0	.6	.07	.05
5-20-73	.75	.10	460	92	1.5	1.25	22	3	0	0	.6	.39	.39
5-23-73	.15	.08	83	13	.02	.01	22	3	0	0	.6	.06	.05
5-24-73	.75	.09	445	80	2.0	1.6	22	3	0	0	.6	.34	.34
6-04-73	.15	.15	131	39	.06	.03	20	5	0	0	.8	.19	.17
6-12-73	.40	.27	301	162	.53	.39	17	8	0	0	.8	.99	.71
6-16-73	.60	.32	463	296	2.5	2.4	15	12	0	0	.9	2.4	1.4
6-17-73	.28	.26	267	139	2.7	2.6	15	12	0	0	.9	1.1	.67
6-21-73	.68	.48	600	576	7.3	6.8	15	16	0	0	1.2	5.7	3.3
6-22-73	.07	.04	30	2	.50	.50	15	16	0	0	1.2	.02	.01
6-24-73	.24	.24	218	105	1.5	1.4	15	16	0	0	1.2	1.0	.60
6-28-73	.60	.42	537	451	12.	11.	15	19	0	0	2.0	5.2	3.3
6-29-73	.34	.15	234	70	3.2	2.8	15	19	0	0	2.0	.80	.51
7-20-73	.60	.39	555	433	4.8	4.6	13	20	0	0	4.0	5.1	4.8
7-25-73	.25	.07	143	20	.05	.04	13	20	0	0	4.0	.24	.22
8-01-73	1.49	.55	1500	1650	26.	24.	12	21	0	0	4.0	20.	18.
8-08-73	.48	.48	557	535	2.8	2.6	12	21	0	0	4.0	6.4	5.9
8-10-73	1.87	1.77	2140	7580	98.	91.	12	23	0	0	4.0	99.	88.
9-14-73	4.80	.42	4000	3360	87.	78.	12	24	0	0	4.0	45.	40.
9-18-73	.80	.54	635	686	13.	12.	12	24	0	0	4.0	9.3	8.1
9-23-73	.25	.17	192	65	1.2	1.2	12	24	0	0	4.2	.88	.81
9-29-73	.32	.09	160	29	.03	.02	12	24	0	0	4.4	.39	.38
10-02-73	.60	.09	350	64	1.2	1.2	10	23	0	0	4.6	.82	.81

Table 1.--Highway construction, precipitation, and sediment data from basin 3, January 19, 1973, to September 28, 1974-(Continued)

Date of storm	Precipitation				Sediment discharge		Area disturbed by highway construction				Average depths of cuts and fills (feet)	Sediment discharge from construction area calculated using	
	Total (inches)	Maximum in 30-minutes (inches)	Kinetic energy (foot-ton/acre)	*EI* (foot-ton-inch/ acre-hour)	total from basin (tons)	from construction area (tons)	cleared and grubbed (acres)	cuts and fills (acres)	seeded and mulched (acres)	paved (acres)		Universal Soil (tons)	Younkin (tons)
10-29-73	1.75	0.31	1230	763	12.	11.	6	27	3	0	4.9	11.	9.6
11-24-72	.20	.13	155	40	.01	.01	2	23	3	0	6.0	.47	.55
11-28-73	.15	.03	73	4	.01	.01	2	23	3	0	6.2	.05	.06
11-28-73	.22	.12	154	37	.26	.24	2	23	3	0	6.2	.44	.53
12-05-73	.70	.08	386	62	2.2	2.1	0	23	3	0	6.4	.71	.87
12-05-73	.18	.16	145	46	3.2	3.1	0	23	3	0	6.4	.53	.65
12-09-73	1.35	.18	914	329	9.1	8.3	0	23	3	0	6.8	3.8	5.0
12-13-73	.25	.05	100	10	.46	.42	0	19	3	0	7.2	.09	.14
12-20-73	1.70	.10	1120	224	9.7	5.7	0	19	3	0	7.3	2.1	3.2
12-26-73	1.10	.08	506	81	4.0	3.0	0	19	3	0	7.3	.77	1.2
1-21-74	1.05	.23	722	332	7.4	5.3	0	19	3	0	7.3	3.2	4.8
1-26-74	.15	.05	131	13	.27	.17	0	19	3	0	7.3	.12	.19
1-28-74	.15	.06	82	10	.26	.20	0	19	3	0	7.3	.09	.14
2-22-74	.95	.25	664	332	14.	12.	0	19	3	0	7.3	3.2	4.8
3-09-74	.27	.09	351	63	.93	.63	0	19	3	0	7.3	.60	.91
3-16-74	.64	.08	378	60	1.0	.80	0	19	3	0	7.3	.57	.87
3-21-74	.80	.15	552	166	4.5	3.0	0	19	3	0	7.3	1.6	2.4
3-30-74	2.4	.15	1470	442	29.	21.	0	19	3	0	7.3	4.2	6.4
4-02-74	.10	.06	55	7	.92	.85	0	19	3	0	7.3	.07	.10
4-04-74	.80	.30	628	377	9.6	6.6	0	19	3	0	7.3	3.6	5.5
4-08-74	.77	.08	370	59	2.5	1.9	0	19	3	0	7.4	.56	.87
4-13-74	.25	.07	149	21	.51	.44	0	19	3	0	7.4	.20	.31
4-14-74	.60	.28	583	326	19.	18	0	19	3	0	7.5	3.2	4.9
5-03-74	.37	.07	175	24	.02	.01	0	18	4	0	7.8	.21	.37
5-09-74	.62	.11	375	82	.22	.16	0	18	4	0	7.8	.74	1.3
5-12-74	1.45	.50	1110	1110	16.	14.	0	18	4	0	7.8	10.	17.
5-22-74	.20	.12	268	107	.03	.01	0	17	5	0	7.9	.91	1.6
5-23-74	.18	.02	85	4	.03	.02	0	17	5	0	7.9	.03	.06
5-27-74	.27	.13	223	58	.27	.24	0	16	6	0	7.9	.46	.82
5-31-74	.65	.08	369	59	.72	.68	0	16	6	0	7.9	.47	.83
6-16-74	1.08	.60	952	1140	7.8	6.6	0	16	6	0	7.9	9.1	16.
6-17-74	.40	.25	339	170	.92	.88	0	16	6	0	7.9	1.4	2.4
6-23-74	1.10	.16	766	245	2.5	2.2	0	14	6	2	7.9	1.7	3.1
6-28-74	.65	.10	415	83	1.4	1.3	0	14	6	2	7.9	.58	1.0
7-01-74	.20	.05	151	15	.01	.01	0	14	6	2	7.9	.10	.19
7-24-74	.45	.12	285	68	.05	.03	0	11	7	4	7.9	.37	.67
7-28-74	.28	.14	202	57	.09	.08	0	11	7	4	7.9	.32	.56
7-29-74	.85	.70	811	1140	11.	10.	0	11	7	4	7.9	6.3	11.
8-02-74	1.12	.60	1080	1290	14.	13.	0	8	7	7	7.9	5.2	8.9
8-03-74	.40	.25	307	153	5.9	5.7	0	8	7	7	7.9	.62	1.1
8-16-74	.98	.97	1050	2040	5.2	4.5	0	8	7	7	7.9	8.2	14.
8-17-74	.08	.08	71	11	.06	.05	0	8	7	7	7.9	.05	.08
8-29-74	.33	.22	302	132	.20	.19	0	5	7	10	7.9	.46	.78
8-30-74	.25	.10	165	33	.13	.12	0	5	7	10	7.9	.11	.20
9-01-74	.80	.45	778	700	7.4	7.3	0	5	7	10	7.9	2.5	4.2
9-03-74	.72	.30	555	333	1.9	1.8	0	5	7	10	7.9	1.3	2.0
9-03-74	.62	.50	621	621	4.4	4.2	0	5	7	10	7.9	2.1	3.7
9-07-74	.73	.08	426	68	.58	.52	0	5	7	10	7.9	.24	.40
9-12-74	.58	.36	536	386	3.8	3.5	0	5	7	10	7.9	1.4	2.3
9-13-74	.50	.26	453	236	2.7	2.2	0	5	7	10	7.9	.83	1.4
9-28-74	.35	.32	305	195	.51	.45	0	5	7	10	7.9	.69	1.2

rainfall erosion soil losses on construction sites and similarly disturbed and unvegetated areas in Pennsylvania," (U.S. Department of Agriculture, 1972). The largest percentage of soils in the basins belong to the Berks-Weikert-Bedington association. The Berks soils represent about 50 percent of the association and have a soil erodibility (K) value of 0.17. The Weikert soils represent 15 percent and have a K value of 0.28, and the Bedington soils represent 5 percent and have a K value of 0.22. Assuming the K values of the remaining soils, which were not classified, have about the same K value, the weighted K value for the association is 0.20.

Highway construction data included the area disturbed by clearing and grubbing, the area in cuts and fills, the average depths of cuts and fills in feet, the area seeded and mulched, and the area paved. All areas were tabulated in acres (table 1).

RESULTS OF CALCULATIONS

Soil losses from the construction area were calculated with the USLE and the following factors were used:

$K = 0.20;$

$(L)\times(S) = 0.28;$

$C = 1.00;$

$P = 0.25$ for the cleared and grubbed area; and

$P = 1.0$ for the area in cuts and fills.

Since the USLE calculates the soil lost instead of sediment discharged, an additional factor must be used to determine how much of the soil was tranported by the stream as sediment. This additional factor is known as the sediment-delivery ratio (DR), and is the sediment discharged during a storm divided by the soil lost during the storm.

Sediment-delivery ratios range from about 1.0 for a very small drainage basin to about 0.10 for a drainage basin larger than 10 mi^2 (Roehl, 1962). Generally, the delivery ratio for the 0.38 mi^2 basin drained by Conodoguinet Creek tributary 3 would be from 0.20 to 0.70. However, because of the extensive drainage system used on highway construction sites, a ratio of 1.00 was chosen for the Conodoguinet Creek tributary 3 data. Using the above factors, the USLE becomes:

$$QS = (DR)(R)(0.20)(0.28)((0.25)(A1)+A2); \qquad (3)$$

where QS = Sediment discharge (tons per storm);

DR = Sediment-delivery ratio;

$R = \frac{EI}{100}$;

A1 = Area in clearing and grubbing (acres); and

A2 = Area in cuts and fills (acres); or

$$QS = 0.056\ (R)\ (0.25A1 + A2)$$

Using the above equation, sediment discharge from the construction area was calculated for each of the 96 storms listed in table 1. The calculated sediment discharges were then plotted against the measured values (fig. 3). The standard error of estimate is 0.40 (about 105 percent), and the coefficient of correlation is 0.79. About 12 percent of the error (50 percent of 25 percent) could be caused by the method of measuring sediment discharge from the construction area. Generally, as can be seen on figure 3, smaller storms produced the greatest difference between measured and calculated values.

Sediment originating from the construction area in basin 3 also was calculated using the Younkin Equation. Soils in the basin had a soil erodibility value (K) of 0.20 which was similar to the (K) value of 0.18 used by Younkin in the development of the equation. A soil-erodibility factor (C2) of 0.129 was used by Younkin and a value of 0.14 was selected for the construction area in the Conodoguinet Creek tributary 3 basin. The proximity factor (P) was 1.0 and the Younkin Equation was reduced to the following form:

$$QS = 0.14(R)(\text{Log } A + 1.0)^{2.80}(1.93)^{D}. \qquad (4)$$

Sediment discharged from basin 3 during construction of Interstate 81 was calculated using the Younkin Equation for the 96 storms (table 1). These values were plotted against measured sediment discharges (fig. 4). The standard error is 0.42 (about 110 percent) and the coefficient of correlation is 0.77. As with the USLE, small storms produced the greatest difference between measured and calculated values.

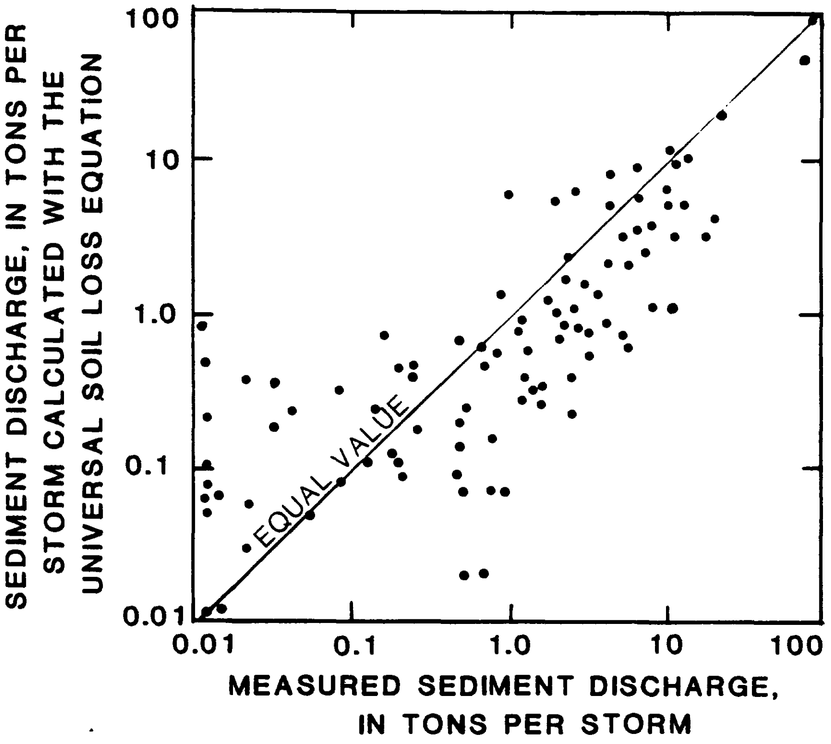

Figure 3.--Relation between measured sediment discharge and calculated sediment discharge using the Universal Soil Loss Equation.

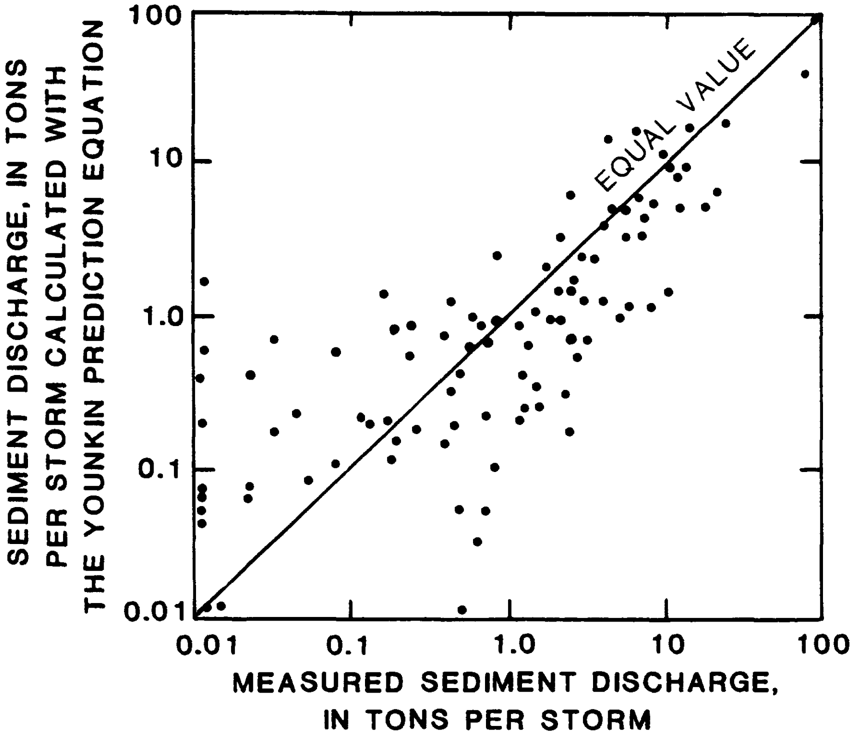

Figure 4.--Relation between measured sediment discharge and calculated sediment discharge using the Younkin Equation.

SUMMARY

The Pennsylvania Department of Transportation, the Federal Highway Adminstration, and the U.S. Geological Survey have cooperated in a study to evaluate two methods of predicting sediment yields during highway construction. Sediment yields were calcuiated using the Universal Soil Loss and the Younkin Sediment Prediction Equations. Results were compared to the actual measured values for storms that occurred during construction of Interstate 81 in a 0.38 mi^2 basin near Harrisburg, Pa. Standard errors and coefficients of correlation were calculated.

The Universal Soil Loss Equation was developed to predict soil losses from cropland (Wischmeier and Smith, 1965); the Younkin Sediment Prediction Equation (Younkin, 1974) was developed to predict sediment discharge from areas affected by highway construction by calculating the quantity of sediment eroded from the exposed surface area not affected by sediment or erosion controls.

For the Universal Soil Loss Equation, the standard error of estimate was 0.40 (about 105 percent), and the coefficient of correlation was 0.79. For the Younkin Equation, the standard error of estimate was 0.42 (about 110 percent), and the coefficient of correlation was 0.77. Generally small storms produced the greatest difference between measured and calculated values, for both equations.

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