ESTIMATING ANNUAL SUSPENDED-SEDIMENT LOADS IN THE NORTHERN AND CENTRAL APPALACHIAN COAL REGION

By G. F. Koltun

U.S. GEOLOGICAL SURVEY

Water Resources Investigations Report 85-4215

Columbus, Ohio

1985

UNITED STATES DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

District Chief
Water Resources Division
U.S. Geological Survey
975 W. Third Avenue
Columbus, Ohio 43212

Copies of this report can
be purchased from:

Open-File Services Section
Western Distribution Branch
U.S. Geological Survey
Box 25425, Federal Center
Denver, Colorado 80225
(Telephone: (303) 236-7476

CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

For the convenience of readers who may prefer to use metric (International System) units rather than the inch-pound units used in this report, values may be converted by using the following factors:

Multiply inch-pound units	By	To obtain metric units
inch (in.)	25.4	millimeter (mm)
mile (mi)	1.609	kilometer (km)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
ton	907.2	kilogram (kg)

ESTIMATING ANNUAL SUSPENDED-SEDIMENT LOADS IN THE NORTHERN AND CENTRAL APPALACHIAN COAL REGION

By G. F. Koltun

ABSTRACT

Multiple-regression equations were developed for estimating the annual suspended-sediment load, for a given year, from small to medium-sized basins in the northern and central parts of the Appalachian coal region. The regression analysis was performed with data for land use, basin characterisitics, streamflow, rainfall, and suspended-sediment load for 15 sites in the region.

Two variables, the maximum mean-daily discharge occurring within the year and the annual peak discharge, explained much of the variation in the annual suspended-sediment load. Separate equations were developed employing each of these discharge variables.

Standard errors for both equations are relatively large, which suggests that future predictions will probably have a low level of precision. This level of precision, however, may be acceptable for certain purposes. It is therefore left to the user to assess whether the level of precision provided by these equations is acceptable for the intended application.

INTRODUCTION

Background

The consequences of erosion are of great economic and environmental importance. Excessive erosion and deposition of sediment causes loss or damage to thousands of acres of farmland, reduction in numbers and diversity of fish species, increased municipal and industrial costs for water purification, reduced conveyance in channels, reduced useful reservoir lifetimes, and other detrimental effects. Damages from all forms of erosion and sedimentation in the United States are estimated to be hundreds of millions of dollars per year (Vanoni, 1975).

Multiple regression techniques can provide a relatively accurate and inexpensive tool for estimating suspended-sediment loads or yields in areas where small quantities of sediment data have been collected. Guy (1964) developed regression equations for predicting suspended-sediment concentration in certain streams of the eastern United States. In a similar analysis, Herb and Yorke (1976) used regression techniques to develop equations for estimating suspended-sediment loads from urban construction sites in the Washington, D.C., area. Flaxman (1972) developed regression equations for predicting sediment yields on streams in the western United States.

Purpose and Scope

The purpose of this report is to present the results of a study designed to develop equations of a general nature for estimating annual suspended-sediment load[1], for a given year, from streams draining small to medium-sized basins in the Appalachian coal region.

Suspended-sediment data collected on a daily basis over a period of 1 or more years at 15 northern and central Appalachian coal-area basins were compiled and analyzed by multiple regression techniques. The resulting equations are intended to be used as a tool for estimating annual suspended-sediment loads in the northern and central Appalachian coal region.

SOURCES OF DATA

Sediment and Streamflow Data

Suspended-sediment data collected by the U.S. Geological Survey are stored in one of two areas in the Water Data Storage and Retrieval (WATSTORE) computer data base. The frequency with which those data are collected determines the area where the data are stored. Suspended-sediment data collected on a daily basis are stored in the WATSTORE daily-values file, and suspended-sediment data collected at other intervals are stored in the WATSTORE water-quality file.

In order to assess data availability for the northern and central Appalachian coal region, "inventory"-type data retrievals were made, which listed sites at which suspended-sediment data had been collected and the number of observations recorded at those sites. The efficiency of the retrievals was improved somewhat by restricting them to the approximate time periods and areas of interest. Area restrictions were imposed by supplying the WATSTORE program with an array of latitude and longitude coordinates that delineated the approximate boundary of the area of interest. Only those sites located within the polygon defined by the latitude and longitude coordinates were retrieved. Time restrictions were imposed by supplying begining and ending dates for the period for which sediment data were desired.

Although sites having full years of daily suspended-sediment data were of primary interest in this study, inventory-type retrievals were made from both the daily-values and water-quality files. The water-quality file inventory indicated that 14,307 sites had suspended-sediment data stored for the time periods and

---

[1] Suspended-sediment load is the mass or weight of suspended sediment that passes through a specified cross section of a stream (generally reported as kilograms or tons).

areas selected for the retrievals. Only 117 of these sites had 10 or more observations recorded. The daily-values file inventory listed 120 sites with daily suspended-sediment data, however, only 103 of these sites had 1 or more full years of suspended-sediment data.

Data on the nature and extent of available suspended-sediment data were provided for informational purposes only. The figures listed above represent data stored in the WATSTORE data base that met the time and area restrictions imposed for the retrievals. Fairly lax time and area restrictions were specified in order to simplify the retrieval process. As a consequence, many of the sites listed in the inventory did not ultimately meet the more stringent time or area restrictions required for this analysis.

Streamflow data also were obtained from WATSTORE daily-values and peak flow files. In most cases, these same streamflow (and sediment) data can be obtained by consulting the U.S. Geological Survey's Water-Data Reports published annually for each state.

Land-Use Data

Land-use data were obtained from L-series maps available through the National Cartographic Information Center. These maps, which are available at a scale of 1:250,000, were generally compiled over a 2- to 3-year period from high-altitude aerial photography. Ten acres is the smallest area mapped for all urban areas, surface mines, quarries, gravel pits, bodies of water, and certain agricultural areas. Forty acres is the smallest area mapped for all other land-use categories. Areas within a land-use category that are smaller than the minimum mapping unit are not identified on the L-series maps.

Land-use data were measured from the L-series maps by means of an electronic digitizer interfaced with a microcomputer. The computer program developed for this purpose was designed to tabulate and summarize level I land-use data (as defined by Anderson and others, 1976) from the L-series maps.

Basin Characteristics

Basin-characteristic data, such as drainage area, main-channel slope, and stream length, were generally obtained from the WATSTORE basin-characteristics file. Those data that were not available through WATSTORE were measured directly from topographic maps. Table 1 defines the basin characteristics and lists the individual sources of data.

Table 1.--Glossary of regressor variables

Regressor variable	Description
AREA	Total drainage area, in square miles, as reported in the WATSTORE header and basin-characteristics files.
SLOPE	Main-channel slope, in feet per mile, computed by the 85- to 10-percent method as described by Benson (1962) or obtained from the WATSTORE basin-characteristics file.
LENGTH	Stream length, in miles, measured along the channel from the gage to the basin divide. Stream-length data were obtained from the WATSTORE basin-characteristics file or measured from 1:250,000 scale topographic maps by means of an electronic digitizer.
I242	(I24,2) precipitation intensity; 24-hour rainfall, in inches, expected on the average of once every two years. I24,2 data were obtained from the WATSTORE basin-characteristics file or from U.S. Weather Bureau Technical Paper 40 (Hershfield, 1961).
PRECIP	Mean annual precipitation, in inches, obtained from the WATSTORE basin-characteristics file.
PEAK	The instantaneous peak discharge, in cubic feet per second, occurring within a given water year. PEAK data were obtained from the WATSTORE peak flow files.
MMDQ	Maximum mean-daily discharge, in cubic feet per second (ft^3/s), occurring within a given water year. MMDQ data were obtained from the WATSTORE daily-values file.
AQ	Annual stream discharge, in second-feet days (sfd), tabulated from data in the WATSTORE daily-values file.
URBAN	Urban lands, in percentage of total drainage area; includes residential, commercial, industrial, and other built-up lands.[1]
AGRIC	Agricultural land, in percentage of total drainage area; includes cropland, pasture, confined feeding operations, and various other horticultural and agricultural areas.[1]
FOREST	Forested land, in percentage of total drainage area; includes deciduous, evergreen, and mixed forests.[1]
BARREN	Barren land, in percentage of total drainage area; includes strip mines, quarries, gravel pits, exposed rock, and other mixed and transitional barren lands.[1]
WETLND	Wetlands, in percentage of total drainage area.[1]
WATER	Water, in percentage of total drainage area; includes streams, canals, lakes, and reservoirs.[1]

[1]All land-use data were measured from L-series maps by means of an electronic digitizer.

Rainfall Data

Two rainfall variables were used in this study: Mean-annual precipitation and the 2-year, 24-hour rainfall (I24,2). These data were obtained either from the WATSTORE basin-characteristics file or from U.S. Weather Bureau technical papers (table 1).

CRITERIA FOR BASIN SELECTION

Data availability was the primary criterion for selecting basins to be used in this analysis. Other factors considered were changing land-use conditions and the presence of upstream regulation. Because of potentially dynamic land-use conditions in basins where data were obtained, analyses of data were restricted to the period that the land-use data were compiled plus or minus 1 year. This 1-year bracketing period was chosen because it provided for a larger data base without severely compromising the validity of the land-use data. Basins with significant upstream regulation or rapidly changing land-use conditions were excluded from this analysis.

Suitable data were available for only 15 sites in the region (fig. 1, table 2). Daily and annual suspended-sediment data were available for other sites; however, those data were not used in the analysis because of rapidly changing land-use conditions, upstream regulation, or other complicating factors.

STATISTICAL ANALYSES

Methods

A multiple regression model was used to evaluate the relationship between annual suspended-sediment load and streamflow, basin characteristics, land-use, and selected rainfall variables. A total of 35 years of annual suspended-sediment load data was compiled for the 15 sites. The SAS procedures REG and STEPWISE were used to perform the regression analyses (SAS, 1982).

Regression Model

Multiple linear regression involves finding an appropriate linear relationship between a response variable (for example, suspended-sediment load) and two or more regressor variables (for example, land-use, basin characteristics, or rainfall variables). This relation, called a multiple regression function, has the general form:

$$Y' = b_0 + b_1 x_1 + b_2 x_2 \ldots + b_n x_n$$

where Y' is the response (dependent) variable,
b_i is the ith (i=0,1,...n) regression coefficient, and
x_j is the jth (j=1,2,...n) regressor variable.

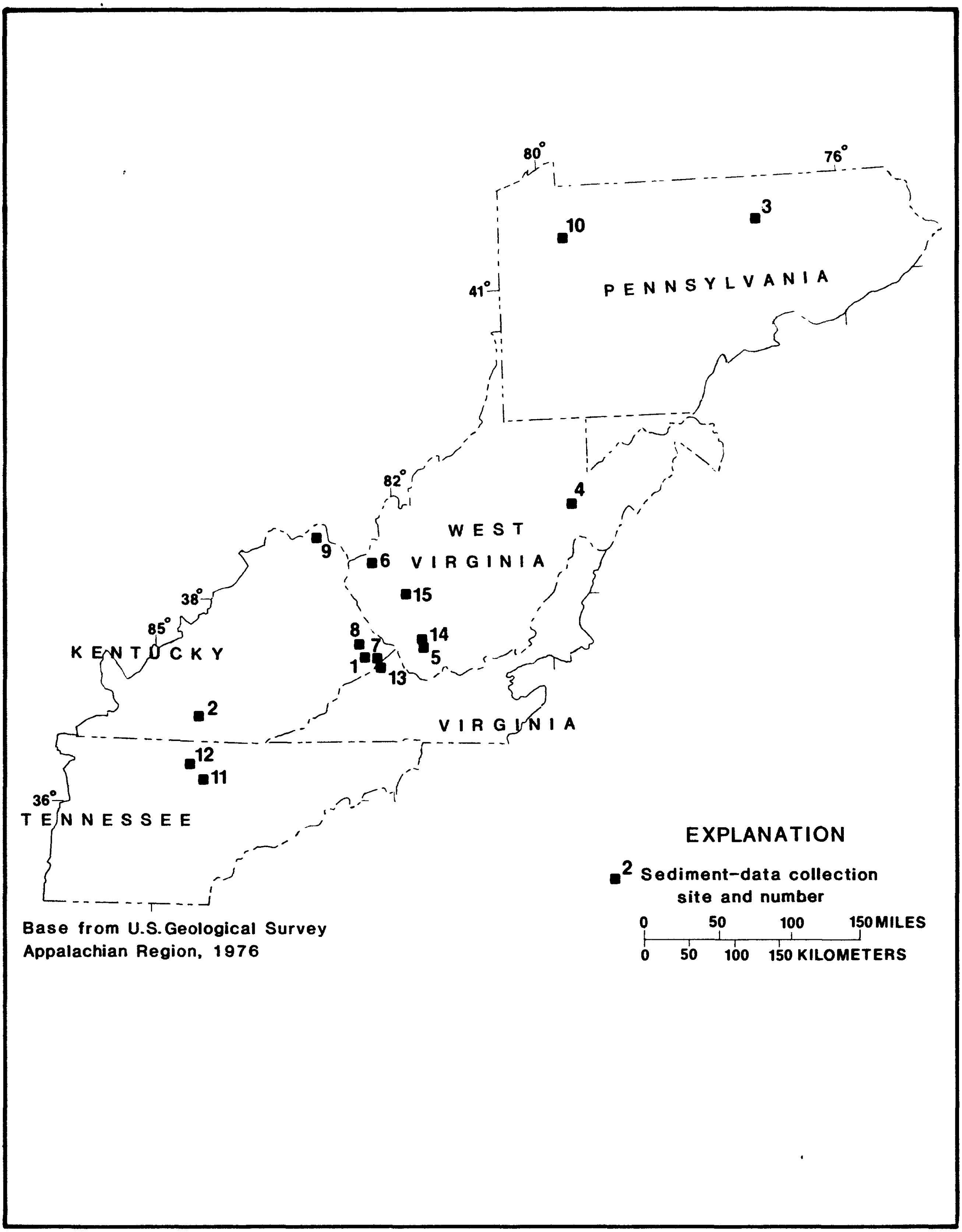

Figure 1.--Location of sites used in the regression analysis.

Table 2.--List of stations used in the analyses

Site number	U.S. Geological Survey station number	Station name	Latitude	Longitude
1	03207962	Dicks Fork at Phyllis, Ky.	372657	0822016
2	03407100	Cane Branch near Parkers Lake, Ky.	365205	0842657
3	01549100	Blockhouse Creek tributary at Liberty, Pa.	413404	0770606
4	03068610	Taylor Run at Bowden, W. Va.	385427	0794149
5	03202490	Indian Creek at Fanrock, W. Va.	373401	0813908
6	03204500	Mud River near Milton, W. Va	382315	0820646
7	03207905	Big Creek at Dunlap, Ky.	372543	0821452
8	03210000	Johns Creek near Meta, Ky.	373401	0822729
9	03217000	Tygarts Creek near Greenup, Ky.	383351	0825708
10	03020500	Oil Creek at Rouseville, Pa.	412854	0794144
11	03407876	Smoky Creek at Hembree, Tenn.	361423	0842448
12	03408500	New River at New River, Tenn.	362308	0843317
13	03207800	Levisa Fork at Big Rock, Va.	372113	0821145
14	03202400	Guyandotte River near Baileysville, W. Va.	373614	0813843
15	03199000	Little Coal River at Danville, W. Va.	380345	0815011

The regression coefficients (b_0, b_1, ... b_n) are computed such that the line represented by the regression equation passes through the data with the least amount of error. Mathematically, the line with the least total error is obtained by minimizing the sum of squared errors, hence the name least-squares regression.

Two statistics of importance in multiple regression analysis are the standard error of estimate and the coefficient of multiple determination. The standard error of estimate is a measure of the dispersion in the data around the regression line. The smaller the standard error of estimate, the more precise estimates of the dependent variable are likely to be. The coefficient of multiple determination is a measure of the proportion of the variation in the response variable that is attributed to the estimated regression line. A coefficient of multiple determination of 1 means that all of the variation in the response is explained by the regression equation. Smaller coefficients of multiple determination indicate that a smaller proportion of the variation in the response is explained by the regression equation.

Analysis of variance, a method of partitioning the variation of a response into its component parts, was used to determine how well a particular model fit the data set. In this procedure, total variation in the response variable about its mean is compared with the variation of the observed responses about the regression line. The regression model is said to fit the data when the variation about the regression line is small compared to the variation about the mean (after being adjusted for the proper degrees of freedom). Similar techniques were used to aid in determining the "best" set of regressor variables to include in the regression model.

Selection of Regressor Variables

Data on several land-use, basin-characteristic, streamflow, and climatic variables that could potentially affect the production and transport of suspended sediment were compiled or computed for use in the analysis (table 1). Complex or hard-to-measure variables were avoided because the objective was to provide a convenient tool for estimating annual suspended-sediment loads.

Regressor variables selected for use in the regression model were required to meet the following criteria:

1.--Each regressor variable must be statistically significant (alpha = 0.05) based on its variance ratio computed in the analysis of variance.

2.--The chosen combination of regressor variables must produce the smallest standard error of estimate while explaining the largest percentage of variation in the response variable.

3.--The resulting regression equation must not violate accepted hydrologic principles.

Results

The data were analyzed graphically before performing the regression analysis. Two-variable scatter plots of the response variable versus the regressor variables were prepared. The scatter plots indicated that logarithmic transformation of the response variable (annual suspended-sediment load) and the water-discharge variables improved the linearity of the relationships.

Two equations were identified that met the selection criteria previously outlined. The first equation employs the variable PEAK, which is the instantaneous annual-peak discharge in cubic feet per second (ft^3/s). The second equation employs the variable MMDQ, which is the maximum mean-daily discharge, in ft^3/s, for the year. Data availability and the desired accuracy will dictate which equations may be used.

The few extreme discharge events that occur during the average year generally contribute a large fraction of the annual suspended-sediment load. For example, a study conducted with data from a 38-station network in Ohio (Anttila and Tobin, 1978) found that 90 percent of the suspended sediment was discharged in only 10 percent of the time. It follows that the maximum mean-daily discharge (MMDQ) and the annual peak discharge (PEAK) would be strongly related to the annual suspended-sediment load.

The discharge variables PEAK and MMDQ explained much of the observed variation in the annual suspended-sediment load. Log-log scatter plots of PEAK and MMDQ and the annual suspended-sediment loads are shown in figures 2 and 3. These plots clearly show the strength of the relationship between these variables and the annual suspended-sediment loads.

Regression equations employing the variables PEAK and MMDQ are presented in power form in table 3 as equations 1 and 2, respectively. The regression lines are plotted on figures 2 and 3 to illustrate how closely the regression equations fit the data. It is evident from figures 2 and 3 that there is an appreciable amount of scatter about the regression lines. The standard errors, a measure of this scatter, were 113 and 136 percent for equations 1 and 2, respectively.

A small reduction in standard error was realized when the variable MMDQ was paired with the variable BARREN. This improvement, however, was not sufficiently great to warrant the added time and effort required for a user to compile the necessary data. As a consequence, this equation is not reported.

Other combinations of variables met the statistical criteria imposed on the model selection; however, the signs or magnitudes of the regression coefficients associated with these variables were not consistent with the underlying hydrologic theory. The apparent statistical significance of these other variables may have been spurious or due to unexplained interaction or surrogate effects.

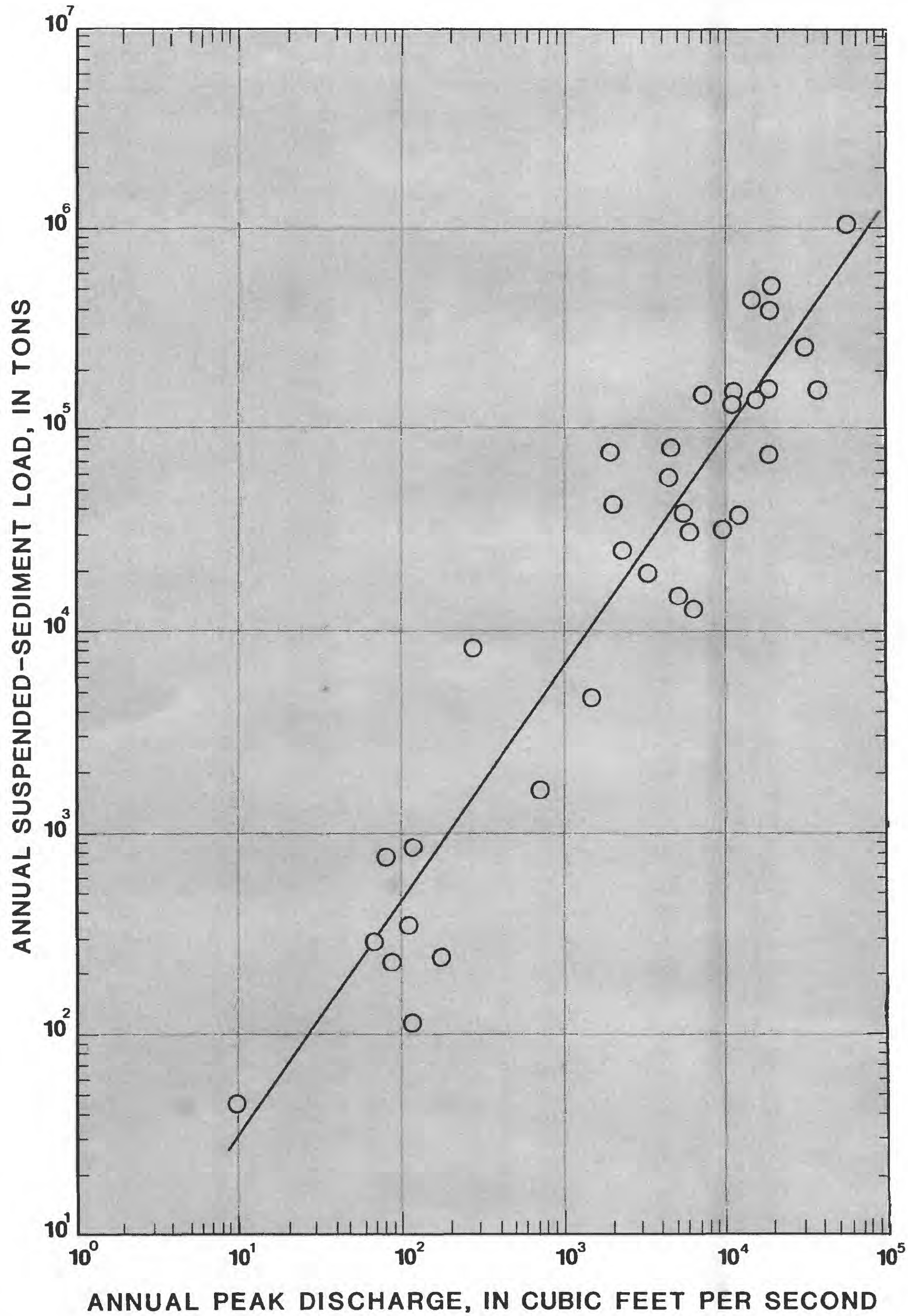

Figure 2.--Scatter plot of annual peak discharge and annual suspended-sediment load showing regression line for equation 1.

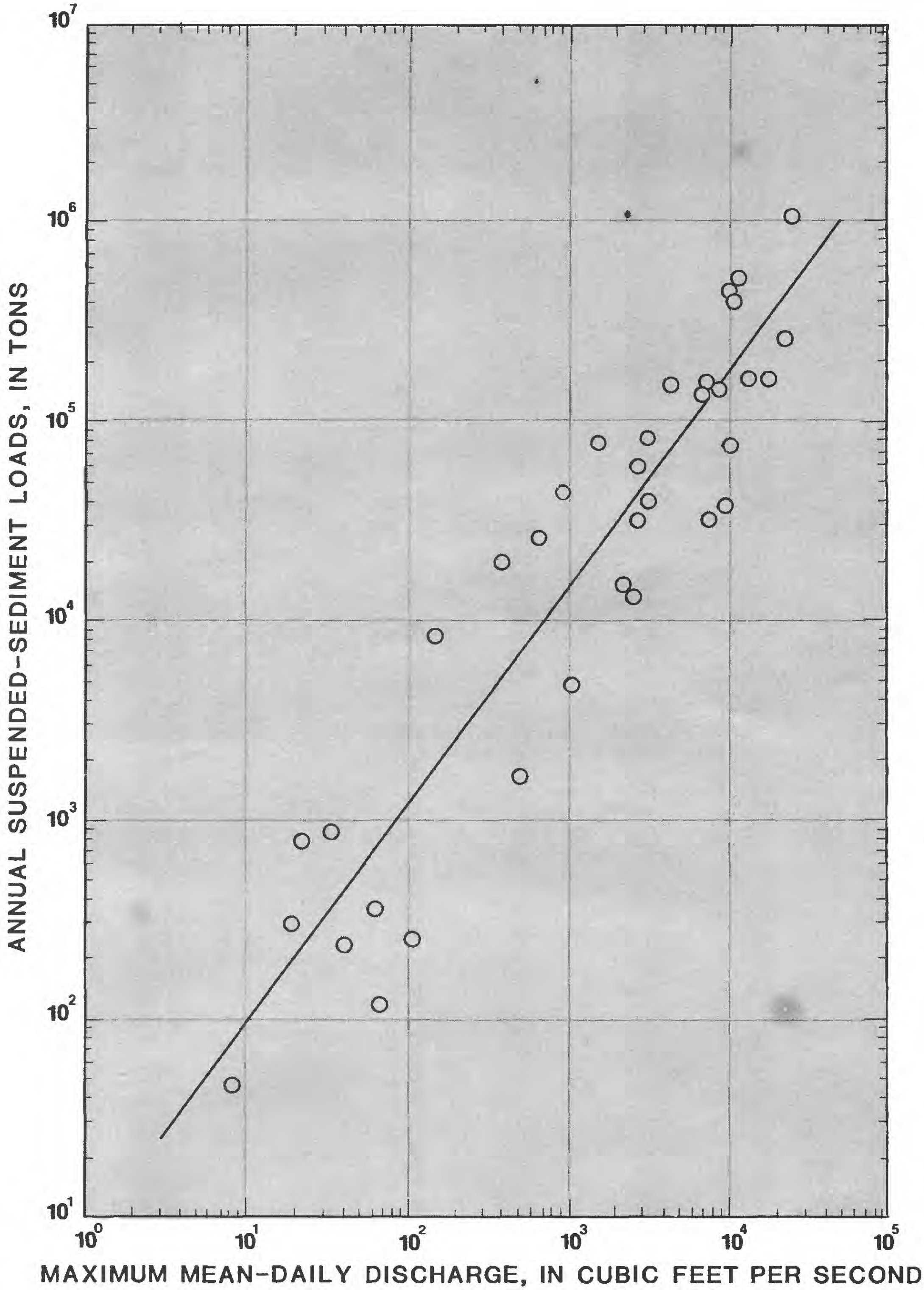

Figure 3.--Scatter plot of maximum mean-daily discharge and annual suspended-sediment load showing regression line for equation 2.

Table 3.--Regression equations for estimating the annual suspended-sediment load for a given year

	Equations	R^2	se%	dfe
(1)	$SEDL = 2.129(PEAK)^{1.166}$	0.89	113	33
(2)	$SEDL = 7.359(MMDQ)^{1.095}$	0.86	136	33

VARIABLES:

- SEDL = Annual suspended-sediment load, in tons.
- PEAK = Peak instantaneous discharge, in cubic feet per second, for the year of interest.
- MMDQ = Maximum mean-daily discharge, in cubic feet per second, for the year of interest.

STATISTICS:

- R^2 = Coefficient of multiple determination.
- se% = Standard error of estimate, expressed as a percentage.
- dfe = Degrees of freedom in the error term.

GUIDELINES FOR USING REGRESSION EQUATIONS

The standard errors for both regression equations are relatively large, which suggests that future predictions will likely have a low level of precision. This level of precision, however, may be acceptable for certain purposes. It is therefore left to the user to assess whether the level of precision provided by these equations is adequate for the intended use.

As with other regression equations, one must be careful not to apply these equations under conditions different than those for which they were developed. Specifically, one would not want to apply these equations to basins with significantly different land use, physiography, or climate than those used to develop the regression equation. For example, it would be unwise to apply these equations at basins in the southern part of the Appalachian coal region, as this area was not represented in the model. Tables 4 and 5 list the data-set characteristics so that the above considerations may be evaluated.

SUMMARY

Selected land-use, basin-characteristic, streamflow, and rainfall data were regressed against annual suspended-sediment loads in order to develop equations for estimating annual suspended-sediment loads from streams in the northern and central Appalachian coal region.

Two equations were presented that may be useful for estimating the annual suspended-sediment loads. The discharge variables, PEAK (the instantaneous annual-peak discharge) and MMDQ (the maximum mean-daily discharge) were used as the sole independent variables in the equations. Both PEAK and MMDQ were found to explain much of the variation in the observed annual suspended-sediment loads.

Standard errors for both equations were relatively large, which suggests that future predictions will probably have a low level of precision. The level of precision provided by these equations may, however, be acceptable for some applications.

A slight reduction in standard error was realized when the variable MMDQ was paired with the variable BARREN. This improvement, however, was not sufficiently great to warrant the additional time and effort required to compile the necessary data and consequently the equation was not reported. Other combinations of variables were found to be statistically significant, but the signs or magnitudes of the regression coefficients were not hydrologically explainable. These equations also were not reported.

Table 4.--Rainfall, basin characteristics, and land-use characteristics

[See table 1 for definitions of variables]

Site	Station	Period of sediment record[1]	Land-use compilation period	Basin characteristics			Rainfall		Land-use characteristics					
				AREA	SLOPE	LENGTH	I242	PRECIP	BARREN	URBAN	AGRIC	FOREST	WETLND	WATER
1	03207962	76-77	73-76	0.82	510	1.46	2.8	44.0	0	0	0	100	0	0
2	03407100	74	73-76	.67	206	1.20	3.2	49.0	0	0	0	100	0	0
3	01549100	73-75	71-74	1.08	96.2	2.08	2.7	39.0	0	0	82.2	15.3	0	2.5
4	03068610	75-76	73-75	5.06	480	2.90	3.0	44.0	0	0.9	0	99.1	0	0
5	03202490	75-77	73-76	41.3	46.9	14.2	2.8	46.0	0	1.4	0	98.6	0	0
6	03204500	76	73-75	256	4.10	48.5	2.7	42.0	0	.3	3.7	96.0	0	0
7	03207905	75	73-76	9.55	102	3.91	2.9	44.0	0.6	0	0	99.4	0	0
8	03210000	75-77	73-76	56.0	24.3	21.5	2.8	44.0	.5	.1	0.5	98.9	0	0
9	03217000	72-73	73-75	242	4.60	61.2	2.8	44.0	.7	1.4	17.7	80.2	0	0
10	03020500	72	73	300	8.45	41.6	2.3	44.7	.1	1.8	26.8	70.4	0.7	0.2
11	03407876	79-80	80-81	17.2	101	5.30	3.4	52.0	16.4	0	2.4	81.2	0	0
12	03408500	80-81	81-81	382	7.06	46.2	3.3	54.0	12.0	.8	3.2	84.0	0	0
13	03207800	74-77	73-76	297	26.5	31.8	2.6	43.5	5.9	.7	.3	93.1	0	0
14	03202400	74-77	73-76	306	35.2	37.5	2.5	43.0	3.7	2.9	2.2	91.2	0	0
15	03199000	74-77	73-76	269	19.7	32.2	2.4	44.0	5.8	2.3	.4	91.5	0	0

[1]Water years

Table 5.--Streamflow and suspended-sediment data

[See table 1 for definitions of variables]

Site	Station	Water year	SEDL	MMDQ	PEAK	AQ
1	03207962	1976	46.1	8.6	9.9	301
		1977	355	65	113	278
2	03407100	1974	784	23	82.0	565
3	01549100	1973	870	35	120	702
		1974	295	20	69	690
		1975	232	42	89	694
4	03068610	1975	248	111	178	6,170
		1976	116	69	118	3,570
5	03202490	1975	4,843	1,110	1,500	28,242
		1976	1,669	528	728	11,721
		1977	13,293	2,670	6,300	21,625
6	03204500	1976	39,909	3,260	5,470	90,006
7	03207905	1975	8,530	154	280	6,890
8	03210000	1975	79,700	1,600	1,950	39,700
		1976	44,000	963	2,030	22,100
		1977	15,500	2,310	5,050	20,400
9	03217000	1972	77,739	10,400	18,200	146,977
		1973	33,087	7,720	9,480	125,829
10	03020500	1972	38,575	9,720	12,000	245,606
11	03407876	1979	26,100	693	2,320	17,800
		1980	20,100	408	3,330	9,770
12	03408500	1980	266,000	22,600	30,800	258,000
		1981	140,000	6,930	10,900	148,000
13	03207800	1974	531,076	11,600	19,200	202,713
		1975	407,937	10,900	18,700	191,020
		1976	84,209	3,250	4,590	81,985
		1977	1,066,955	24,800	56,000	148,814
14	03202400	1974	167,579	13,400	18,600	226,190
		1975	161,403	7,420	11,200	224,297
		1976	32,153	2,830	5,950	104,234
		1977	165,433	17,900	36,700	171,528
15	03199000	1974	458,141	10,100	14,600	202,611
		1975	155,889	4,490	7,240	183,340
		1976	60,094	2,840	4,450	99,845
		1977	148,343	8,780	15,200	119,177

SELECTED REFERENCES

Anderson, J. R., Hardy, E. E., Roach, J. T., and Witmer, R. E., 1976, A land use and land cover classification system for use with remote sensor data: U.S. Geological Survey Professional Paper 964, 28 p.

Anttila, S. M., and Tobin, R. L., 1978, Fluvial sediment in Ohio: U.S. Geological Survey Water-Supply Paper 2045, 58 p.

Benson, M. A., 1962, Factors influencing the occurrence of floods in a humid region of diverse terrain: U.S. Geological Survey Water-Supply Paper 1580-B, 64 p.

Brush, L. M., Jr., 1961, Drainage basins, channels, and flow characteristics of selected streams in central Pennsylvania: U.S. Geological Survey Professional Paper 282, p. 160-181.

Colby, B. R., 1956, Relationship of sediment discharge to streamflow: U.S. Geological Survey Open-File Report, 24 p.

Davies, O. L., and Goldsmith, P. L., 1972, Statistical methods in research and production: Edinburgh, Oliver and Boyd, 478 p.

Flaxman, E. M., 1972, Predicting sediment yield in western United States: Journal of the Hydraulics Division, American Society of Civil Engineers, v. 98, no. 12, p. 2073-2085.

Gunst, R. F., and Mason, R. L., 1980, Regression analysis and its application -- A data-oriented approach: New York, Marcel Dekker, 402 p.

Guy, H. P., 1964, An analysis of some storm-period variables affecting stream sediment transport: U.S. Geological Survey Professional Paper 462-E, 46 p.

Hack, J. T., 1957, Studies of longitudinal stream profiles in Virginia and Maryland: U.S. Geological Survey Professional Paper 294-B, 97 p.

Herb, W. J., and Yorke, T. H., 1976, Storm period variables affecting sediment transport from urban construction areas: Proceedings, Third Federal Interagency Sedimentation Conference, p. 1.181-1.192.

Hindall, S. M., 1975, Measurement and prediction of sediment yields in Wisconsin streams: U.S. Geological Survey Water-Resources Investigation 54-75, 27 p.

Lystrom, D. J., Rinella, F. A., Rickert, D. A., and Zimmerman, Lisa, 1978, Multiple regression modeling approach for regional water quality management: U.S. Environmental Protection Agency, EPA-600/7-78-198, 59 p.

Miller, C. R., 1951, Analysis of flow-duration, sediment-rating curve method of computing sediment yield: U.S. Bureau of Reclamation, Hydrology Branch, Project Planning Division, 55 p.

Montgomery, D. C., and Peck, E. A., 1982, Introduction to linear regression analysis: New York, Wiley, 504 p.

SAS Institute Inc. , 1982, SAS User's Guide -- Statistics: Cary, North Carolina, 584 p.

U.S. Department of Commerce, 1961, Rainfall frequency atlas of the United States: Washington, D.C., U.S. Weather Bureau Technical Paper No. 40, 115 p.

Vanoni, V. A., 1975, Sedimentation engineering: American Society of Civil Engineers Manual and Report on Engineering Practice no. 54, 745 p.