COMPARISON OF SEDIMENT TRANSPORT FORMULAS AND COMPUTATION OF SEDIMENT DISCHARGES FOR THE NORTH FORK TOUTLE AND TOUTLE RIVERS, NEAR MOUNT ST. HELENS, WASHINGTON

A PRELIMINARY REPORT

By Stephen E. Hammond

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CONVERSION FACTORS

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

Multiply inch-pound unit	By	To obtain metric unit
foot (ft)	0.3048	meter (m)
foot per second (ft/s)	0.3048	meter per second (m/s)
foot cubed per second (ft^3/s)	0.02832	meter cubed per sec (m^2/s)
pound (lb)	0.4536	kilogram (kg)
tons per day (tons/day)	907.2	kilograms per day (kg/day)

COMPARISON OF SEDIMENT TRANSPORT FORMULAS AND COMPUTATION OF SEDIMENT DISCHARGES FOR THE NORTH FORK TOUTLE AND TOUTLE RIVERS, NEAR MOUNT ST. HELENS, WASHINGTON

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ABSTRACT

This preliminary report presents results of computations using twelve different sediment-discharge formulas along with data from two sites in the Toutle River system. Ultimately, the results will be used to assess the ability of the formulas to predict proper sediment discharges in the study streams. In this report, however, the results of the computations are presented graphically for comparison purposes only. In addition to output from the formulas, the results from suspended-sediment samples and several bedload measurements using a pressure-differential type bedload sampler are presented. All units are in pound-foot-second units. No interpretation of the information is provided.

INTRODUCTION

Following the 1980 eruptions of Mount St. Helens, a variety of sediment-transport phenomena was investigated and documented in the Toutle River basin. The U.S. Geological Survey's Water Resources Division project office, located at the Cascades Volcano Observatory (CVO), in cooperation with the U.S. Army Corps of Engineers (COE), has undertaken the task of estimating sediment discharges for the Toutle River by transport formula. Ultimately, the results of this study will be used to assess the ability of the formulas to predict proper sediment discharges in the study streams. The purpose of this preliminary report is to present results of computations using several different formulas with river-hydraulic and sediment-characteristic data from two sites in the Toutle River system. Measured bedload-discharge rates from data collected with a Helly-Smith type bedload sampler also are included.

Of the large number of transport formulas designed to estimate sediment discharge in rivers, twelve are presented in this report. The formulas have been classified by the general concept or dominant variable used in deriving the equations and by the type of output from the equations.

A total of 43 data sets from two sites has been used with the transport formulas. The results of the computations are presented graphically. In addition to these computed sediment-transport rates, the results from several measurements using a Helley-Smith type bedload sampler are presented. All units are in lbs-ft-sec (pounds-feet-seconds).

Error sources in the theoretical methods, based on analysis of bed-material characteristics, channel geometry, and hydrologic factors are undefined. Also, questions with regard to the trap-efficiency of the Helley-Smith bedload sampler used under the conditions found in the Toutle River system remain to be answered. As a consequence, figures of bedload discharge must be used with caution. They are estimates, at best, and are subject to revision.

TRANSPORT FORMULAS

Twelve transport formulas have been assembled to compute instantaneous sediment discharges in the North Fork Toutle River and the Toutle River. Six of the formulas were used to compute the bed-material-discharge rate. Bed-material is defined as the mass of sediment particles whose sizes are the same as those present in the bed, and is transported past a cross section in a unit of time. The other six formulas were used to compute the bedload-discharge rate, defined as the mass of tractive load passing a cross section in a unit length of time. The formulas classified by type of output are shown in table 1.

Table 1.-Transport formulas classified by type of output

Type of output	Procedure
Bed-material discharge	Ackers and White(1973) Modified Einstein (Colby and Hembree,1955, Burkham and others,1977, Stevens,1985) Engelund and Hansen(1967) Laursen(1958) Toffaletti(1969) Yang (sand equation)(1972)
Bedload discharge	Einstein(1950) Kalinske(1947) Meyer-Peter and Muller(1948) Mizuyama(1977) Schoklitsch (1950, Shulitz,1968) Yang (gravel equation)(1984)

Each transport formula is based on a general concept, such as the probability of particle movement, or on a dominant variable, such as water discharge, which is needed to produce the motion of sediment particles in a stream. The formulas have been classified (table 2) by the general concept or the dominant variable used in deriving the equation. For example, the Schoklitsch equation is based on unit water discharge and the critical unit water discharge above which particle motion begins.

***Table 2.**-Transport formulas classified by the general concept or dominant variable used in deriving the formula*

General concept or dominant variable	Procedure
Water discharge	Schoklitsch
Relative roughness	Laursen
Tractive force	Kalinske Meyer-Peter and Muller Engelund and Hansen Mizuyama
Probability of particle movement	Einstein Modified Einstein Toffaletti
Energy expenditure	Ackers and White Yang sand equation Yang gravel equation

DESCRIPTION OF DATA

Data used in these computations were collected at the gaging station located on the North Fork Toutle River near Kid Valley, Washington (KIDV), and on the Toutle River at Tower Road near Silver Lake, Washington (TOWR), between WYs (water years) 1982-85 (fig. 1). The data include a wide range of flow and transport conditions. Each data set includes hydraulic parameters derived from water-discharge measurements, sediment concentration and particle-size distribution of suspended-sediment samples, and particle-size distribution of bed-material samples. Data collected between WY's 1982-84 are presented along with station descriptions by Childers and others (1987).

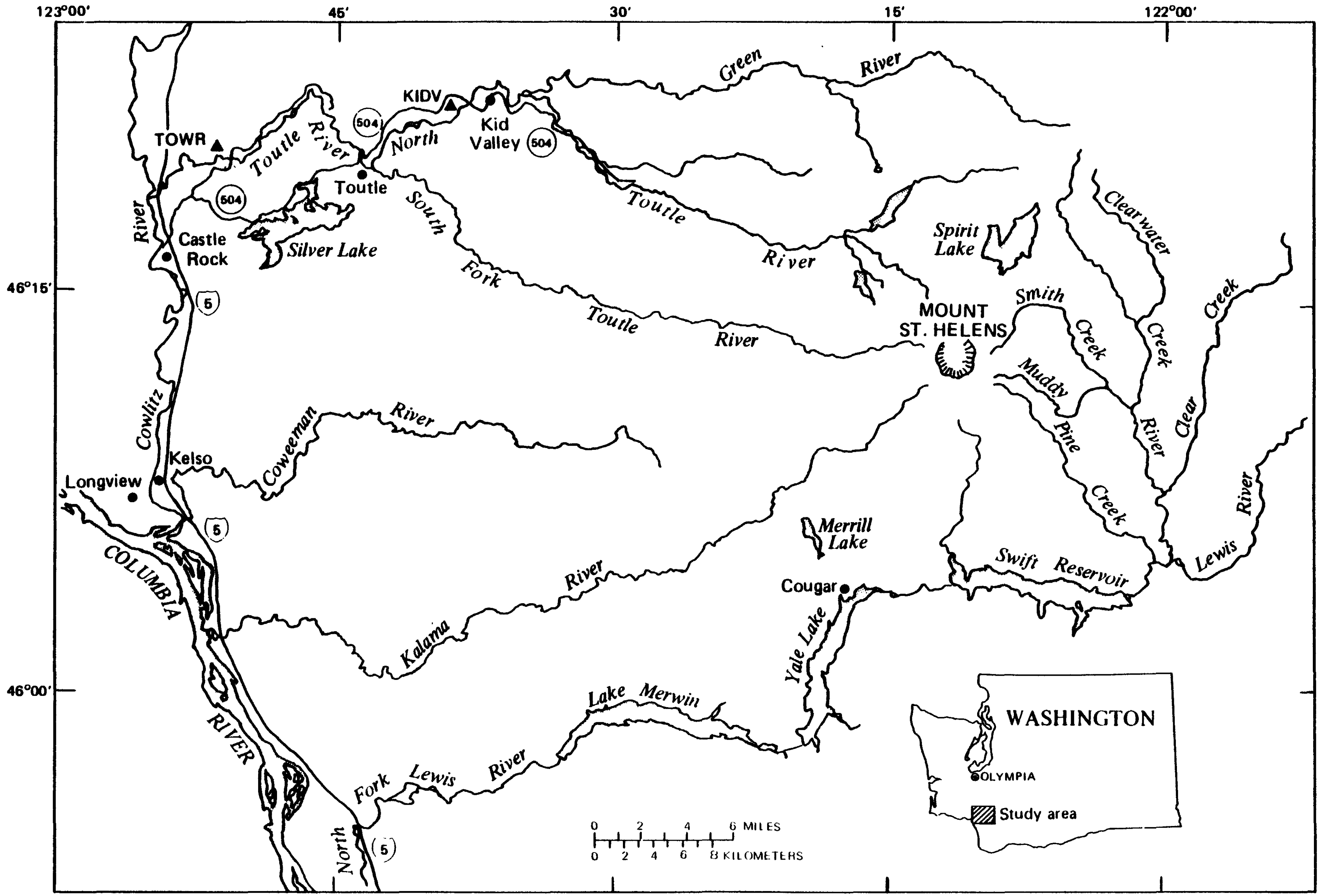

Figure 1-. Map showing locations of gaging-station sampling sites in the Toutle River basin, Mount St. Helens, Washington.

In WY 1985, data collection at both gaging stations was expanded to include the regular sampling of bedload with the 3-inch Helley-Smith (Helley and Smith, 1971) bedload sampler. Although the measured bedload rates are estimates of sediment transport, they permit a general comparison with which transport rates computed by formula can be made.

Measured bedload-discharge values presented in this report are unadjusted because field calibration of the Helley-Smith bedload sampler in the Toutle River is incomplete. However, calibration of the sampler in a laboratory flume (Hubbell, D.E., U.S. Geological Survey, oral communication, 1986) and a field calibration on the East Fork River, Wyoming, by Emmett (1979), have shown the sampler's trap-efficiency can vary from 100 percent. Therefore, it is possible that actual bedload-discharge rates in the Toutle River may differ from the measured rates.

General information about each data set which was used for the computation of bed-material discharge and bedload discharge at the gaging stations on the North Fork Toutle River near Kid Valley and Toutle River at Tower Road near Silver Lake are presented in tables 3 and 4, respectively. Measured suspended-sediment-discharge and measured bedload-discharge rates are expressed in terms of tons per day, however, all of the values shown in tables 3 and 4 are instantaneous values for the point in time in which they were measured.

COMPUTED SEDIMENT LOADS

Each formula was used to compute transport rates at each site. These transport rates were then plotted against the instantaneous water discharge using logarithmic scaling on both axes. The graphs for the North Fork Toutle River near Kid Valley are presented in figures 2-6. The graphs for the Toutle River at Tower Road near Silver Lake are presented in figures 7-11. The best-fit regression lines in figures 2-11 are shown only for purposes of comparison and should not be construed as interpretation of the relations.

Bed-material discharges computed using the Engelund and Hansen formula and the best-fit curve obtained using regression techniques applied to computed numbers for the North Fork Toutle River and Toutle River data, respectively, are shown in figures 2 and 7. The data points trend from the lower left to the upper right of the graphs. These graphs are typical of trend and scatter of the output for each of the other formulas except those of Toffaletti and Kalinske.

Bed-material discharges computed with the Toffaletti formula and corresponding regression line are shown in figures 3 and 8. These data exhibit much more scatter than the other formulas. Output from the Kalinske formula showed a similar amount of scatter.

Table 3.-Listing of general information related to the sets of data collected on the North Fork Toutle River near Kid Valley, Washington

[D_{50}: particle size that 50 percent of the material, by weight, is finer than. Abbreviated units: ft^3/s, feet cubed per second; ft/s, feet per second; ft, feet; ft/ft, feet/foot; mg/L, milligrams per liter; mm, millimeters.]

Date	Water discharge (ft^3/s)	Mean velocity (ft/s)	Mean depth (ft)	Water-surface slope (ft/ft)	Suspended-sediment concentration (mg/L)	Measured suspended-sediment discharge (tons/day)	Suface bed-material D_{50} (mm)	Measured bedload discharge (tons/day)
1-29-82	2,450	6.86	2.06	.00384	7,500	49,600	0.86	---
2-16-82	10,600	10.10	5.73	.00321	49,500	1,420,000	0.95	---
2-22-82	4,610	8.37	3.06	.00239	22,000	274,000	0.50	---
3-31-82	963	5.70	0.95	.00490	18,200	47,300	0.49	---
4-29-82	1,500	5.83	1.40	.00465	6,940	28,100	1.07	---
5-24-82	1,310	5.82	1.61	.00433	4,100	14,500	2.91	---
6-23-82	798	5.62	1.03	.00500	4,400	9,480	2.55	---
2- 8-83	1,040	5.81	1.55	.00480	8,720	24,500	0.92	---
12-30-83	2,310	6.77	1.83	.00490	17,200	107,000	1.18	---
1- 4-84	4,480	7.47	3.16	.00370	21,400	259,000	1.41	---
2-21-85	1,030	5.83	1.57	.00485	3,380	9,400	0.21	1,900
3- 6-85	1,010	5.77	1.62	.00465	2,600	7,090	0.91	1,230
3-26-85	1,270	5.91	1.84	.00370	4,350	14,900	3.23	2,650
4-11-85	2,220	7.14	2.66	.00438	9,040	54,200	1.56	6,950
4-30-85	1,640	6.46	2.19	.00455	3,160	14,000	4.79	7,280
5-31-85	1,370	6.68	2.21	.00452	12,600	46,600	1.93	4,110
6- 7-85	6,040	9.04	3.61	.00377	29,100	475,000	2.07	10,500

Table 4.-Listing of general information related to the data sets collected on the Toutle River at Tower Road near Silver Lake, Washington

[D_{50}: particle size that 50 percent of the material, by weight, is finer than. Abbreviated units: ft^3/s, feet cubed per second; ft/s, feet per second; ft, feet; ft/ft, feet/foot; mg/L, milligrams per liter; mm, millimeters.]

Date	Water discharge (ft^3/s)	Mean velocity (ft/s)	Mean depth (ft)	Water-surface slope (ft/ft)	Suspended-sediment concentration (mg/L)	Measured suspended-sediment discharge (tons/day)	Suface bed-material D_{50} (mm)	Measured bedload discharge (tons/day)
12-15-81	5,900	7.93	3.51	.00280	12,800	204,000	0.61	---
1-17-82	10,100	7.83	6.25	.00340	12,200	333,000	2.13	---
2- 9-82	1,830	5.65	1.71	.00167	1,610	7,960	0.78	---
2-16-82	17,100	10.70	7.25	.00407	30,500	1,410,000	0.54	---
3-29-82	1,760	6.01	1.40	.00307	11,500	54,600	0.55	---
9-15-82	522	3.02	0.84	.00273	2,280	3,210	0.92	---
10-29-82	8,070	8.89	3.98	.00337	26,000	567,000	0.70	---
1-10-83	8,550	8.93	4.18	.00327	14,000	323,000	0.69	---
3- 7-83	2,780	6.48	1.99	.00208	10,600	79,600	0.69	---
3-30-83	7,570	8.52	3.95	.00240	13,800	282,000	0.64	---
9-21-83	573	4.41	1.46	.00288	1,490	2,310	0.93	---
11- 4-83	6,590	8.80	3.43	.00288	39,000	694,000	0.81	---
11-22-83	4,760	7.58	2.92	.00197	10,900	140,000	0.62	---
12- 5-83	2,080	6.32	1.84	.00287	7,790	43,700	0.53	---
1-24-84	13,000	9.92	5.67	.00377	33,000	1,160,000	0.59	---
1-26-84	8,160	8.27	4.41	.00279	17,600	388,000	0.57	---
2- 1-84	2,410	6.36	1.76	.00212	9,760	63,500	0.71	---
3-29-84	3,620	6.79	2.49	.00257	6,480	63,300	0.71	---
6- 7-84	2,170	6.40	2.22	.00290	7,060	41,400	0.58	---
7-27-84	853	4.47	1.91	.00280	4,860	11,200	0.61	---
1-31-85	1,020	4.08	3.42	.00280	2,080	5,730	0.81	1,130
2-21-85	1,650	5.71	3.08	.00280	2,430	10,800	1.52	5,130
3-27-85	2,220	5.59	2.31	.00234	2,960	17,700	0.92	3,340
4- 2-85	3,040	6.04	2.50	.00241	3,050	25,000	0.69	6,470
5-24-85	2,240	5.73	2.26	.00233	9,660	58,400	0.97	1,640
8-23-85	547	5.06	1.90	.00280	2,390	3,530	0.48	320

The best-fit regression lines for the six bed-material-discharge formulas along with the measured suspended-sediment discharges and the measured bedload discharges are shown in figures 4 and 9. It appears, from the figures, that the Modified Einstein, Engelund and Hansen, and Yang sand formulas may give useful estimates of bed-material discharge for these data sets.

The best-fit regression lines for the six bedload-discharge formulas together with the measured suspended-sediment discharges and the measured bedload discharges are shown in figures 5 and 10. It appears, from the figures, that the Schoklitsch formula may provide appropriate estimates of bedload discharge for these data sets.

The best-fit regression lines for the six bed-material-discharge formulas and the six bedload-discharge formulas, along with the measured suspended-sediment and bedload-discharge data on a single plot, are shown in figures 6 and 11. The output from a bed-material-discharge formula cannot be compared directly with that of a bedload formula; however, these figures show the differences in magnitude of transport rates computed with the two groups of formulas.

SUMMARY

This report illustrates output from a variety of sediment-discharge formulas using data collected from the North Fork Toutle and Toutle Rivers. An interpretive report detailing the results of the investigation is in preparation.

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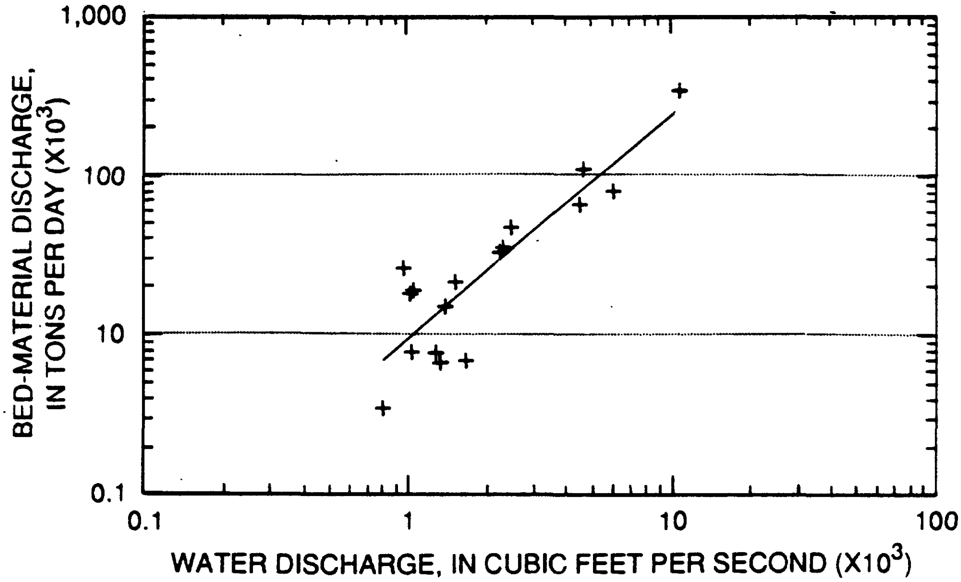

Figure 2.- Variation of bed-material discharge computed using the Engelund and Hansen formula with water discharge, North Fork Toutle River near Kid Valley, Washington.

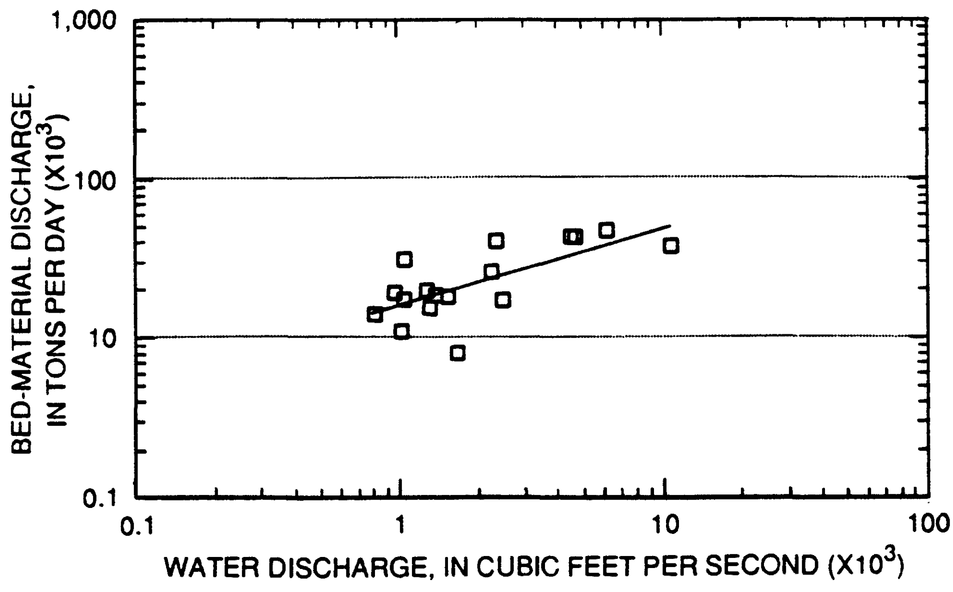

Figure 3.- Variation of bed-material discharge computed using the Toffaletti formula with water discharge, North Fork Toutle River near Kid Valley, Washington.

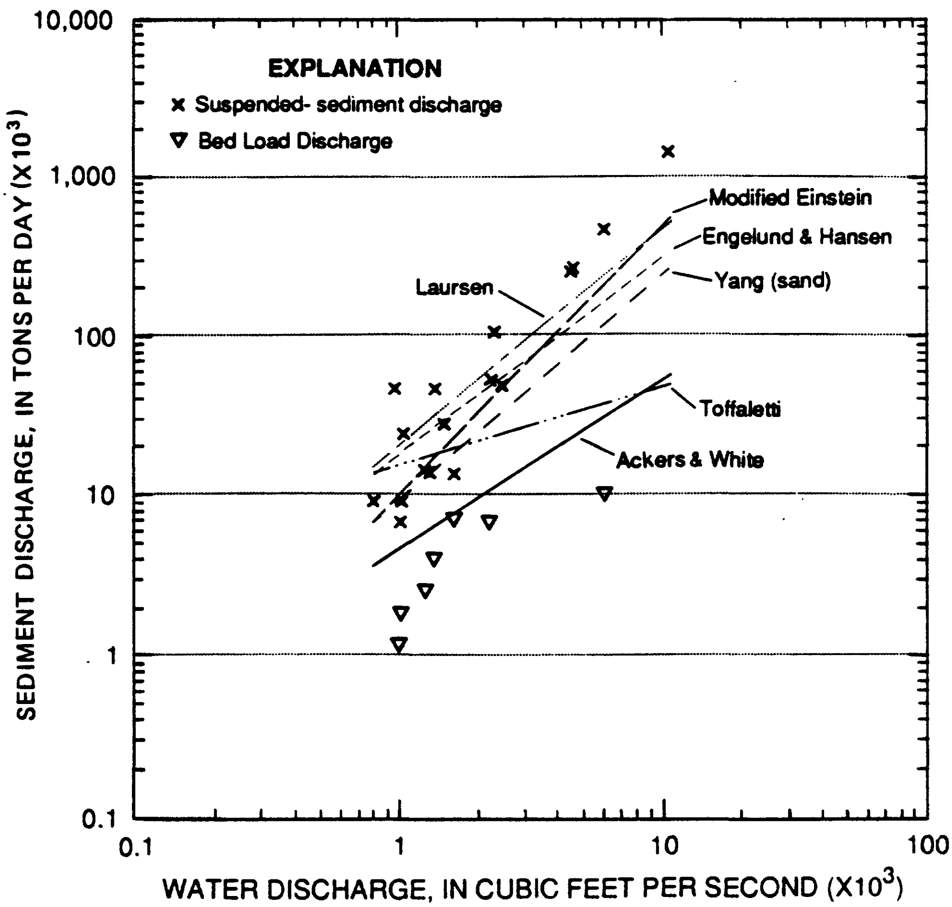

Figure 4.- Best-fit regression lines for six bed-material-discharge formulas and variation of measured suspended-sediment discharge and measured bedload discharge with water discharge, North Fork Toutle River near Kid Valley, Washington.

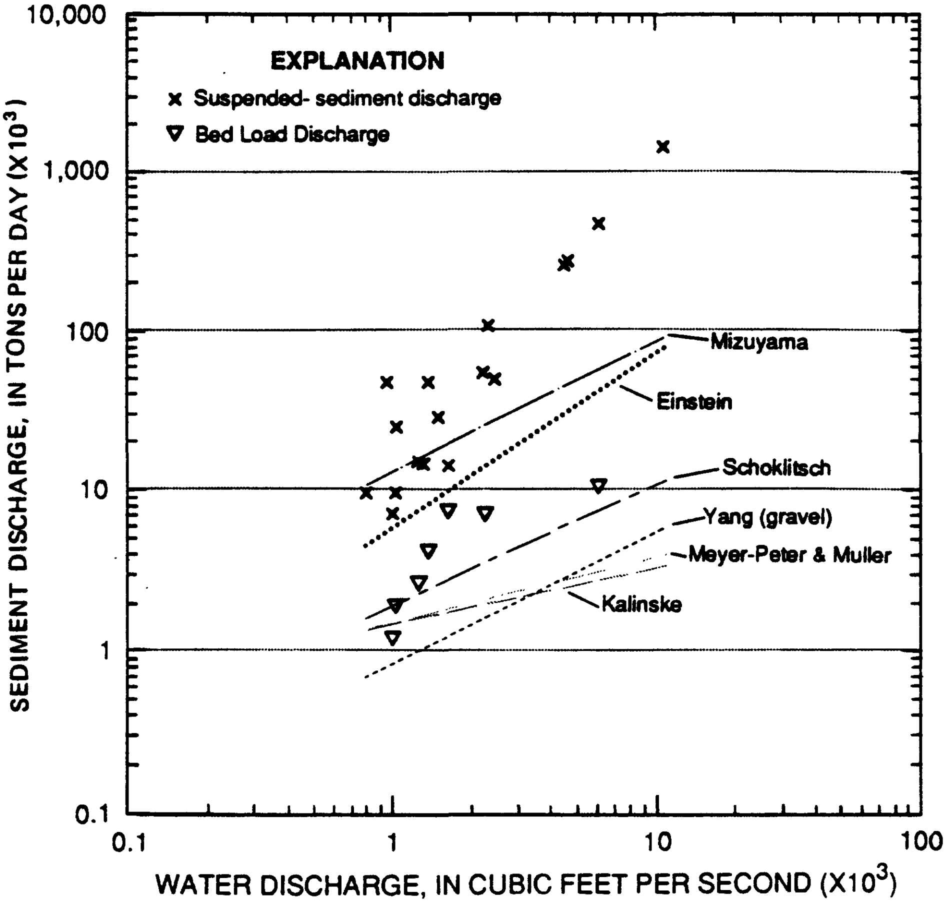

Figure 5.- Best-fit regression lines for six bedload-discharge formulas and variation of measured suspended-sediment discharge and measured bedload discharge with water discharge, North Fork Toutle River near Kid Valley, Washington.

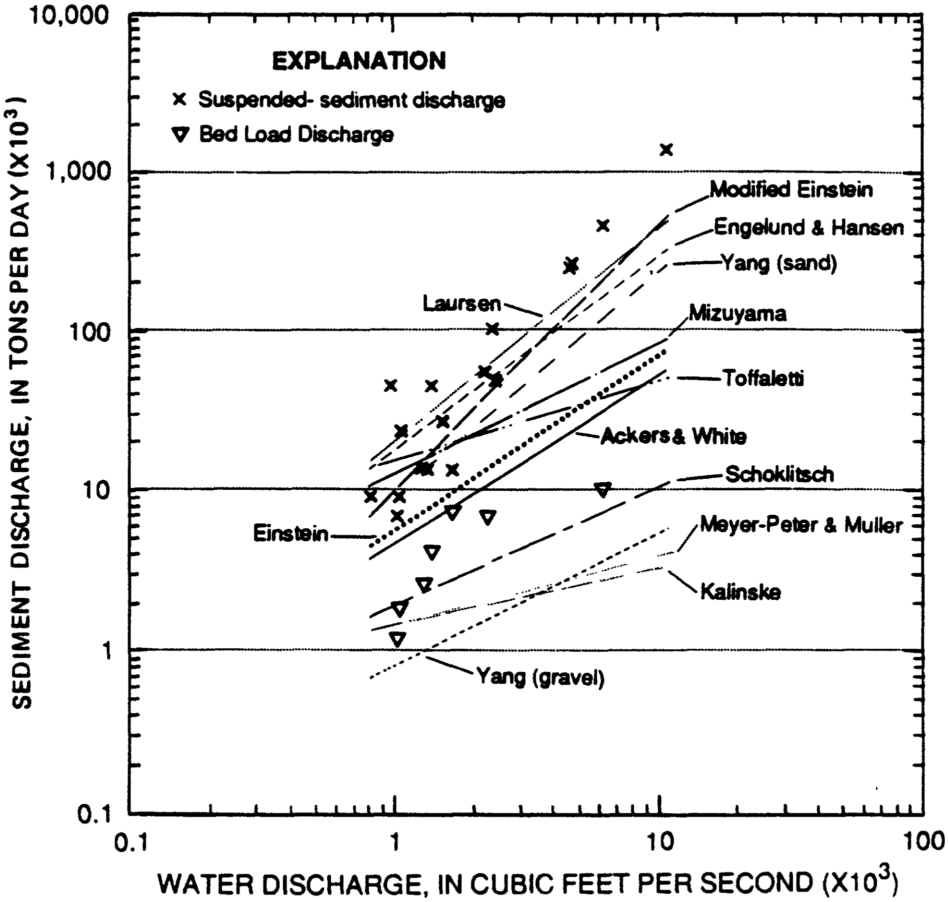

Figure 6.- Best-fit regression lines for six bed-material-discharge formulas, six bedload-discharge formulas, and variation of measured suspended-sediment discharge and measured bedload discharge with water discharge, North Fork Toutle River near Kid Valley, Washington.

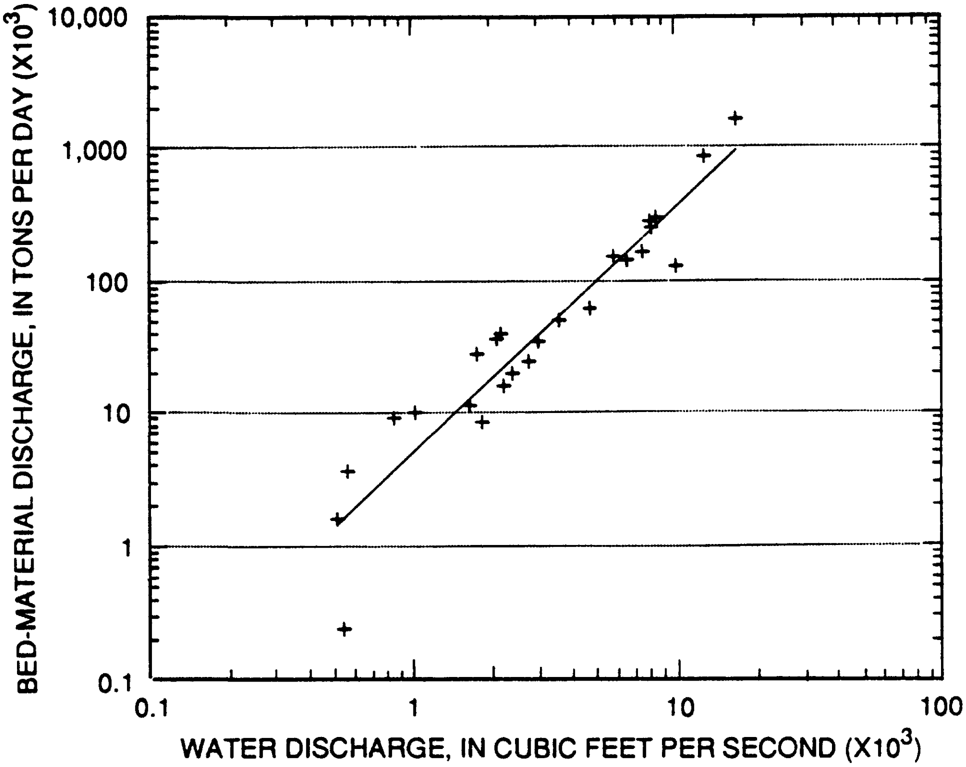

Figure 7.- Variation of bed-material discharge computed using the Engelund and Hansen formula with water discharge, Toutle River at Tower Road near Silver Lake, Washington.

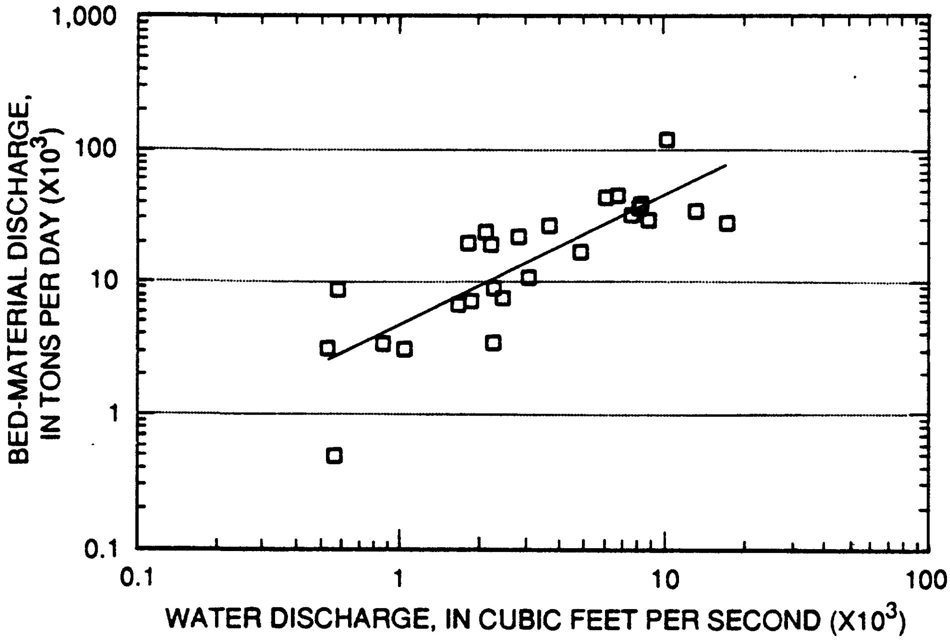

Figure 8.- Variation of bed-material discharge computed using the Toffaletti formula with water discharge, Toutle River at Tower Road near Silver Lake, Washington.

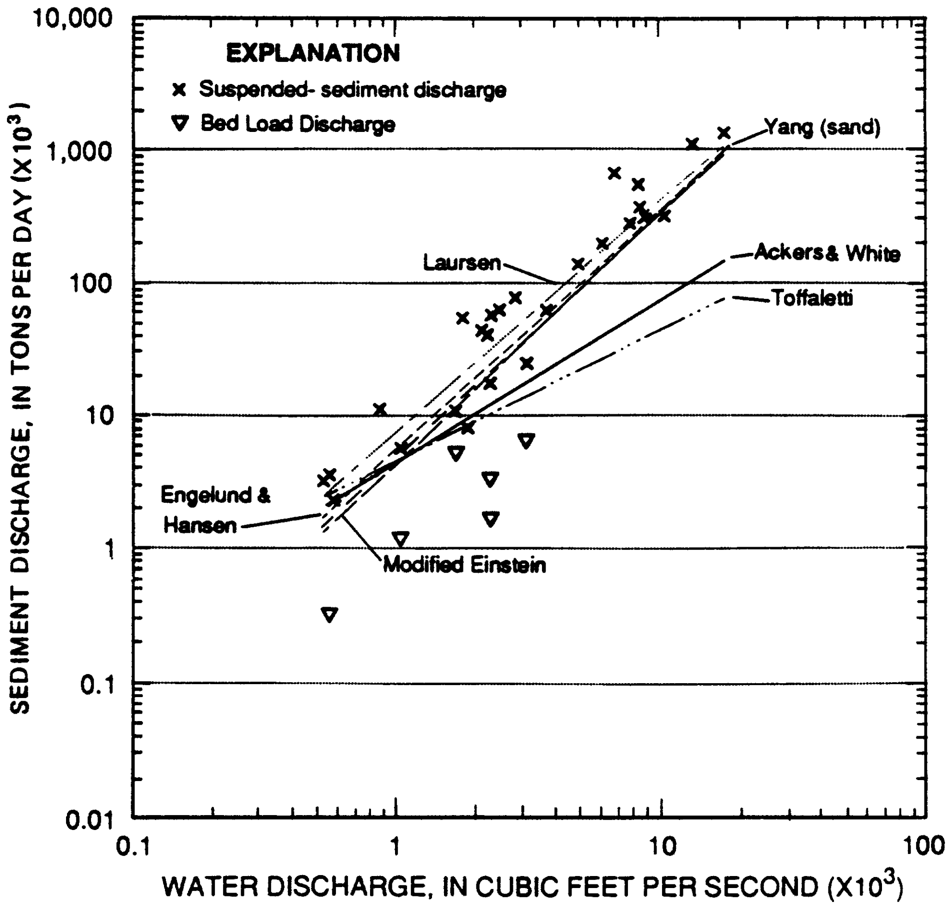

Figure 9.- Best-fit regression lines for six bed-material-discharge formulas and variation of measured suspended-sediment discharge and measured bedload discharge with water discharge, Toutle River at Tower Road near Silver Lake, Washington.

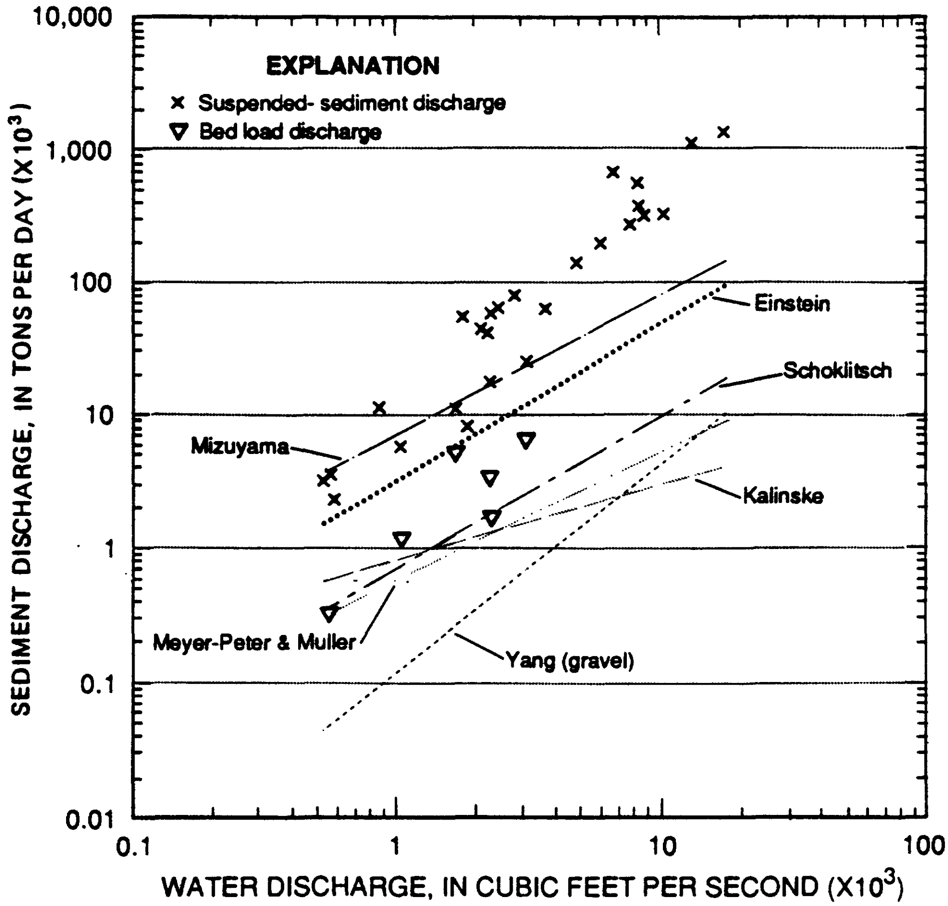

Figure 10.- Best-fit regression lines for six bedload-discharge formulas and variation of measured suspended-sediment discharge and measured bedload discharge with water discharge, Toutle River at Tower Road near Silver Lake, Washington.

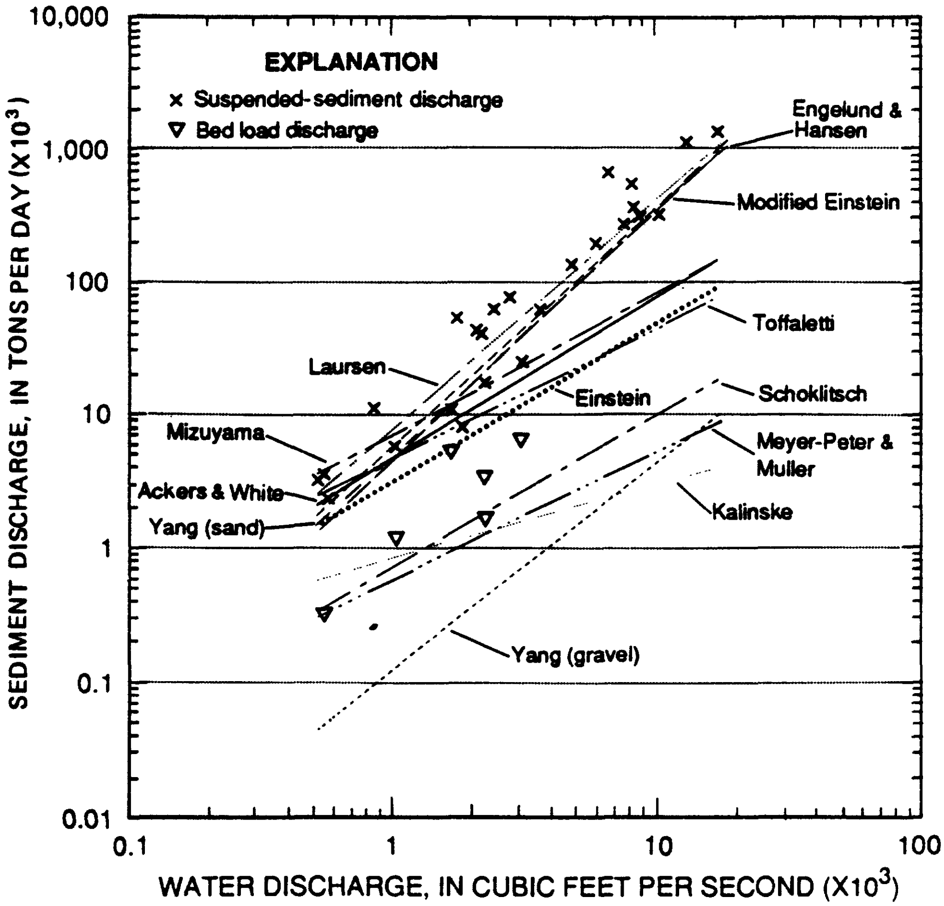

Figure 11.- Best-fit regression lines for six bed-material-discharge formulas, six bedload-discharge formulas, and variation of measured suspended-sediment discharge and measured bedload discharge with water discharge, Toutle River at Tower Road, near Silver Lake, Washington.