EVALUATION OF SEDIMENT YIELD AND SEDIMENT DATA-COLLECTION NETWORK IN THE PICEANCE BASIN, NORTHWESTERN COLORADO

By James E. Kircher and Paul Von Guerard

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Table 3.--*Statistics and coefficients for regressions of instantaneous suspended-sediment discharge versus instantaneous water discharge at stations in the Piceance and Yellow Creeks drainage basins*

Station No.	Average standard error, in percent	Coefficients for equation of formula: $\text{Log } Q_s = \text{Log } a + b \text{ Log } Q$		Range of water discharge	
		a	*b*	Minimum	Maximum
09306007	160	0.03	2.15	0.600	520.0
09306028	71.0	1.12	1.19	0	38
09306033	224	121	2.47	0	7
09306058	144	.23	1.68	0	23
09306061	135	.01	2.42	0	492
09306175	156	.06	2.10	.2	72
09306200	117	.02	2.23	.21	400
09306222	153	.03	2.03	.5	628
09306240	346	1.37	1.66	0	30
09306241	121	7.20	1.23	0	5
09306242	371	.44	2.35	.06	183
09306244	287	1.42	1.90	0	60
09306246	25.7	8.98	1.72	.80	11
09306255	182	.27	2.06	0	6800

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GLOSSARY

Annual peak.--The highest peak discharge during a water year.

Basin characteristics.--Physical and climatic conditions of the basin. The basin characteristics defined for this study include:

Drainage area, in square miles, computed from the latest U.S. Geological Survey topographic maps.

Main-channel length, in miles to the nearest 0.1 mile from the streamflow-gaging station to the divide, as measured from the latest U.S. Geological Survey topographic maps.

Main-channel slope, in feet per feet, determined from the latest U.S. Geological Survey topographic maps from elevations at points 10 percent and 85 percent of the distance along the channel from the streamflow-gaging station to the divide (Benson, 1964).

Drainage density, in miles per square miles, the ratio of the total length of channels divided by the drainage area determined from the latest U.S. Geological Survey topographic maps.

Basin length, in miles, the airline distance from the basin outlet to the point on the basin divide used to determine main channel length (Office of Water Data Coordination, 1977).

Average basin slope, in percent, based on the average of 25 or more slopes taken at points on an equal-spaced grid pattern laid over 1:50,000-scale topographic maps (Lystrom and others, 1978).

Percent of basins having slopes greater than 20 percent, based on 25 or more points from an equal-spaced grid pattern laid over 1:50,000-scale topographic maps (Lystrom and others, 1978).

Average basin elevation, in feet above the National Geodetic Vertical Datum of 1929, determined from 30 or more equal-spaced grid points from the most recent U.S. Geological Survey topographic maps.

Forest cover, expressed as a percentage of the drainage area determined from the latest U.S. Geological Survey topographic maps by the grid method.

Mean annual precipitation, in inches to the nearest 0.1 inch, determined as a mean for the basin from an isoheyetal U.S. Weather Bureau map (Iorns and others, 1965).

The maximum 24-hour rainfall having a recurrence interval of 2 years, expressed in inches to the nearest 0.1 inch, determined as a mean for the basin from a U.S. Weather Bureau map (Iorns and others, 1965).

Correlation.--Degree of linear association of two or more random variables.

Correlation coefficient.--A mathematical definition of the degree of linear association between two variables. The degree of correlation may range from 0 (no correlation) to plus or minus one (total correlation). The plus or minus sign indicates whether the variables are directly (plus) or inversely (minus) related. The correlation coefficient is an indicator of the amount of variation explained by the independent variables used in the regression. The remaining variance is unaccounted for and due to neglected random variables.

Ephemeral stream.--A stream that usually flows only in direct response to precipitation. Such a stream receives no water from springs and no long continued supply from melting snow or other surface source. Its channel is above the water table.

Frequency.--The number of occurrences of a certain phenomenon in a given period of time.

Intermittent stream.--A stream or reach of a stream that flows only part of the year when it receives water from springs or from surface flows during wet weather or from melting snow.

Mean.--The arithmetic average of the values of a variable.

Mean annual discharge.--The average of a series of annual water discharges, in cubic feet per second.

Mean annual suspended-sediment discharge.--The average of a series of annual sediment discharges, in tons per day.

Mean monthly discharge.--The average of a series of monthly water discharges, in cubic feet per second.

Mean monthly suspended-sediment discharge.--The average of a series of monthly sediment discharges, in tons per day.

Monthly mean discharge.--The average of a particular month's water discharges--usually the average of the month's daily flows, expressed in cubic feet per second.

Monthly mean precipitation.--In this report it is the monthly precipitation at the Little Hills Game Experiment Station, in inches.

Monthly mean suspended-sediment discharge.--The average of a particular month's sediment discharges--usually the average of the month's daily sediment discharges, expressed in tons per day.

Normalize.--To transform a variable so that the probability distribution of the transformed variable approximates a normal distribution.

Parameter.--A descriptive measure of a population, such as an average, a measure of variability, or a regression coefficient.

Perennial stream.--A stream that flows continuously during all seasons of the year and during dry as well as wet years. Such a stream usually is fed by ground water.

Residual.--The vertical departure from the observed value to the regression estimate.

Significance.--A statistical test of the hypothesis that a dependent variable is sufficiently explained by an independent variable at a certain predetermined level of significance.

Skewness.--A measure of the asymmetry of a frequency distribution.

Standard deviation.--Descriptor of dispersion of values about a central value. The standard deviation is an indicator of the variability of the observed values.

Standard error of estimate.--Standard deviation of the variables about the regression line used to predict the dependent variable. Approximately two-thirds of the data values for the dependent variable are included within plus and minus one standard error of the estimate made by the regression equation.

Stationary.--A variable is stationary if the distribution is constant with respect to time.

Stepwise regression.--A multiple-regression technique that tests all independent variables for significance with respect to the dependent variable and adds the most significant variable to the regression equation. Then additional independent variables are tested and added if they meet the prespecified level of significance. Each step also retests those variables already in the model and removes them if the significance level is below that specified for the model. This process continues until an equation is derived with all the variables significant at the predetermined level.

Water year.--The 12-month period, October 1 through September 30. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the water year ending September 30, 1981, is called the 1981 water year.

CONVERSION FACTORS

Inch-pound units used in this report may be converted to SI (International System) units by using the following conversion factors:

Multiply	*By*	*To obtain*
acre	0.4047	hectare
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
pound (lb)	0.454	kilogram
square mile (mi^2)	2.590	square kilometer
ton (short)	0.9072	ton

National Geodetic Vertical Datum of 1929: A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level.

EVALUATION OF SEDIMENT YIELD AND SEDIMENT DATA-COLLECTION NETWORK IN THE PICEANCE BASIN, NORTHWESTERN COLORADO

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ABSTRACT

Statistical relationships were developed between suspended-sediment discharge and several regional factors of climate, physiography, and land use in the Piceance basin, northwestern Colorado. The existing sediment-collection network was evaluated, especially in regard to detecting changes in suspended-sediment discharge due to the development in the basin. Spatial and time variability were examined using multiple linear-regression techniques. Because of the short period of record, monthly mean sediment loads were used to determine shifts or changes in trends due to mining and related activities in the basin. Dummy variable analysis was used to detect these premining and postmining differences in the regression lines and also to detect seasonal differences in the sediment discharge.

Differences did exist in the sediment discharge from season to season and before and after mining; however, due to the variability and short period of record the cause of these differences could not be adequately determined. Part of the high variability in sediment discharge was due to variability in the water discharge. Therefore, if the network is to be improved, the emphasis needs to be on improvement of the water-discharge records and the relations between suspended-sediment discharge and water discharge.

The results of the monthly mean regression analysis were used in the mean monthly and mean annual analysis for determination of initial network-design equations. These were only preliminary in nature and could be improved with additional data.

INTRODUCTION

Background

Oil-shale mining disrupts the native soils, vegetation, and landforms as a result of road construction, overburden removal, and disposal of spoils. The associated potential changes in erosion, sediment transport, and deposition are of concern to local, State, and Federal managers and to the mining industry.

Oil-shale development in the Piceance basin in northwestern Colorado could involve the mining, processing, and disposal of more than 150,000 tons of oil shale per day. To monitor premining conditions and the hydrologic effect of proposed oil-shale development in the Piceance basin, 29 daily streamflow and suspended-sediment stations have been established and operated since the mid-1970's. Most of the record was collected prior to mining development; however, 2 years of record exist following the beginning of development.

Purpose

The purpose of this report is to evaluate the existing sediment-collection network, especially with regard to its capability of detecting changes in sediment transport due to mining. The analysis to be presented consists of the following steps: (1) Determine if there have been any changes resulting from the mining development, and (2) determine if adequate predictive equations can be developed using the existing data base. A consequence of these determinations could be a network analysis which would indicate a possible network expansion or contraction. Hydrologic network design concerns the allocation of resources for obtaining a desired level of information (in terms of the reliability of the estimates). Because temporal and spatial patterns of economic development are uncertain, a requirement of the hydrologic network is that it provide estimates of hydrologic parameters for sites at which data are not available.

Scope

The scope of this study was to (1) compile the existing information in a form that could be readily analyzed, (2) document the methods used to compile the sediment data and basin characteristics that affect sediment yield, (3) examine the feasibility of using multiple-regression analysis for information transfer to ungaged streams, (4) determine any apparent changes that may have occurred in the basin, and (5) perform a preliminary network analysis of the Piceance basin which will serve as input into an extended network evaluation. The results of this study are limited to the Piceance and Yellow Creeks basin; however, the approach is applicable to similar studies of other areas. The technical terms and abbreviations used in this report are defined in the "Glossary."

Acknowledgments

The authors would like to thank Michael R. Karlinger and Brent M. Troutman for their many stimulating discussions and assistance in the statistical analysis, which materially aided in the success of this study.

BASIN SETTING

The study area includes the Piceance and Yellow Creeks drainage basin and is in Rio Blanco and Garfield Counties southwest of Meeker, Colo. (fig. 1). In this report, these two drainage basins are referred to as the Piceance basin or simply as the basin. The Piceance basin has a total drainage area of 892 mi^2. Elevations in the basin range from 5,535 ft at the mouth of Yellow Creek to 9,300 ft at the headwaters of Piceance Creek.

Geology and Soils

The Piceance basin is part of a structural basin containing shale, sandstone, and marlstone of the Wasatch Formation of Paleocene and Eocene age and the overlying Green River Formation of Eocene age. The lower part of the Uinta Formation (Eocene) is exposed over much of the area (Frickel and others, 1975).

Soils of the Piceance basin tend to be sandy, very permeable, and not highly erodible, unless they occur on steep slopes or are subject to intense rainfall. These soils are calcareous, and the depth to bedrock ranges from 20 to 40 in. The depth to bedrock is greater in the valley bottoms, and the soils there have higher percentages of silt and clay (A. L. Jones, U.S. Soil Conservation Service, oral commun., 1981).

Climate

The climate of the basin is semiarid. Annual precipitation ranges from 12 to 25 in. A plot of the total monthly precipitation at the Little Hills Game Experiment Station (fig. 1), elevation 6,440 ft, is shown in figure 2. The mean annual precipitation (1970 through 1979) at this station was 13.17 in. (U.S. Department of Commerce, 1970-79). The greatest monthly average precipitation is 1.49 in. October). The least monthly average precipitation is 0.45 in. (February). Intense, localized thunderstorms of short duration are a major source of precipitation between June and October. Temperatures in the basin range from -40°F to 104°F.

Surface-Water Hydrology

The average annual runoff (1974-79) for the Piceance basin is 29.4 ft^3/s. During years of nearly average precipitation, Piceance Creek, three to four tributaries, and Yellow Creek are perennial. The remaining tributaries and the upper reaches of all streams in the basin are intermittent or ephemeral (fig. 3).

Normally, peak flows on the perennial streams in the basin are a result of snowmelt. During years of extreme low winter snowpack, peak flows on perennial streams are a result of summer thunderstorms. Peak discharges on intermittent or ephemeral streams are normally the result of thunderstorms (table 1).

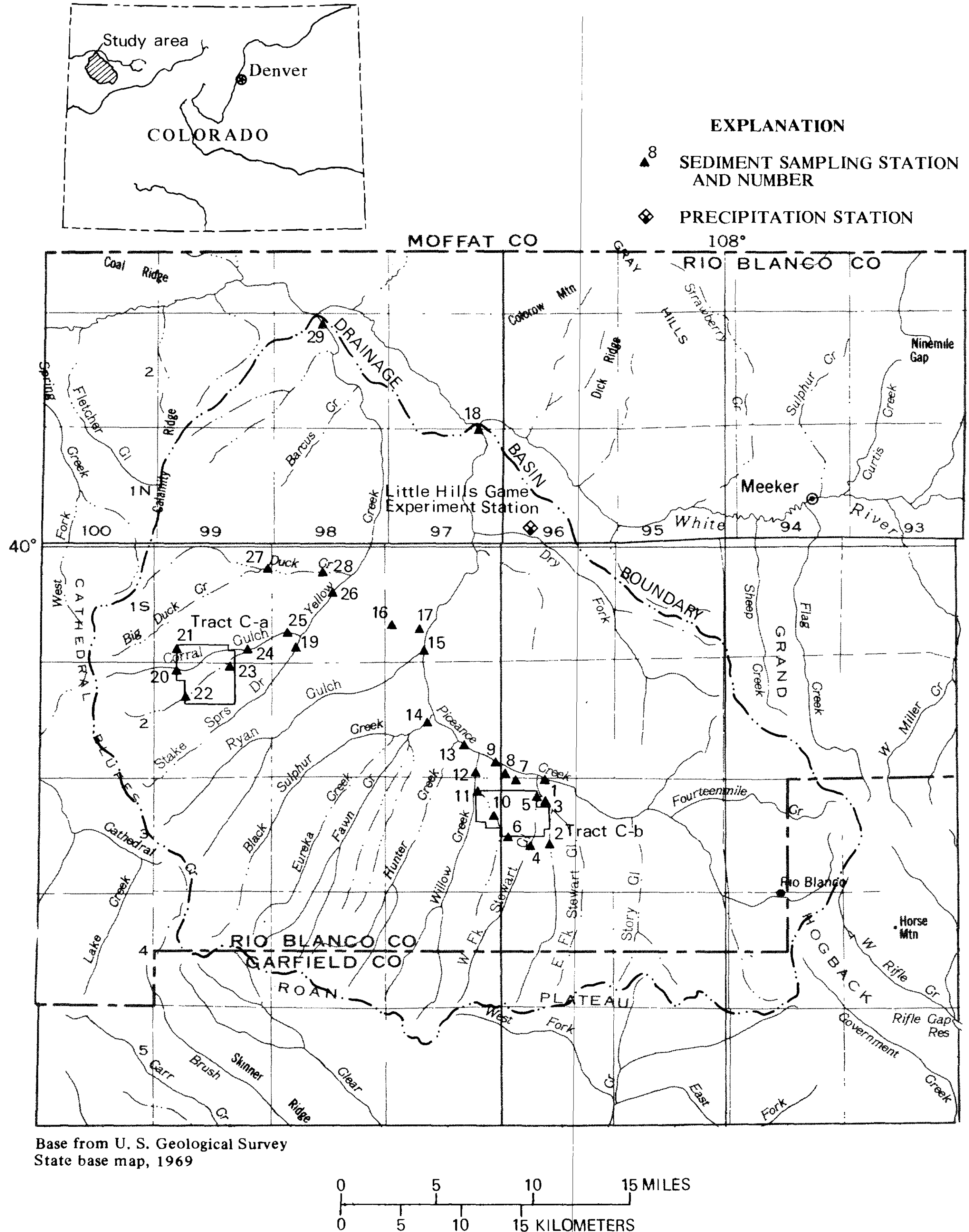

Figure 1.--Location of sediment-sampling stations and the precipitation station at the Little Hills Game Experiment Station in the Piceance and Yellow Creeks drainage basin.

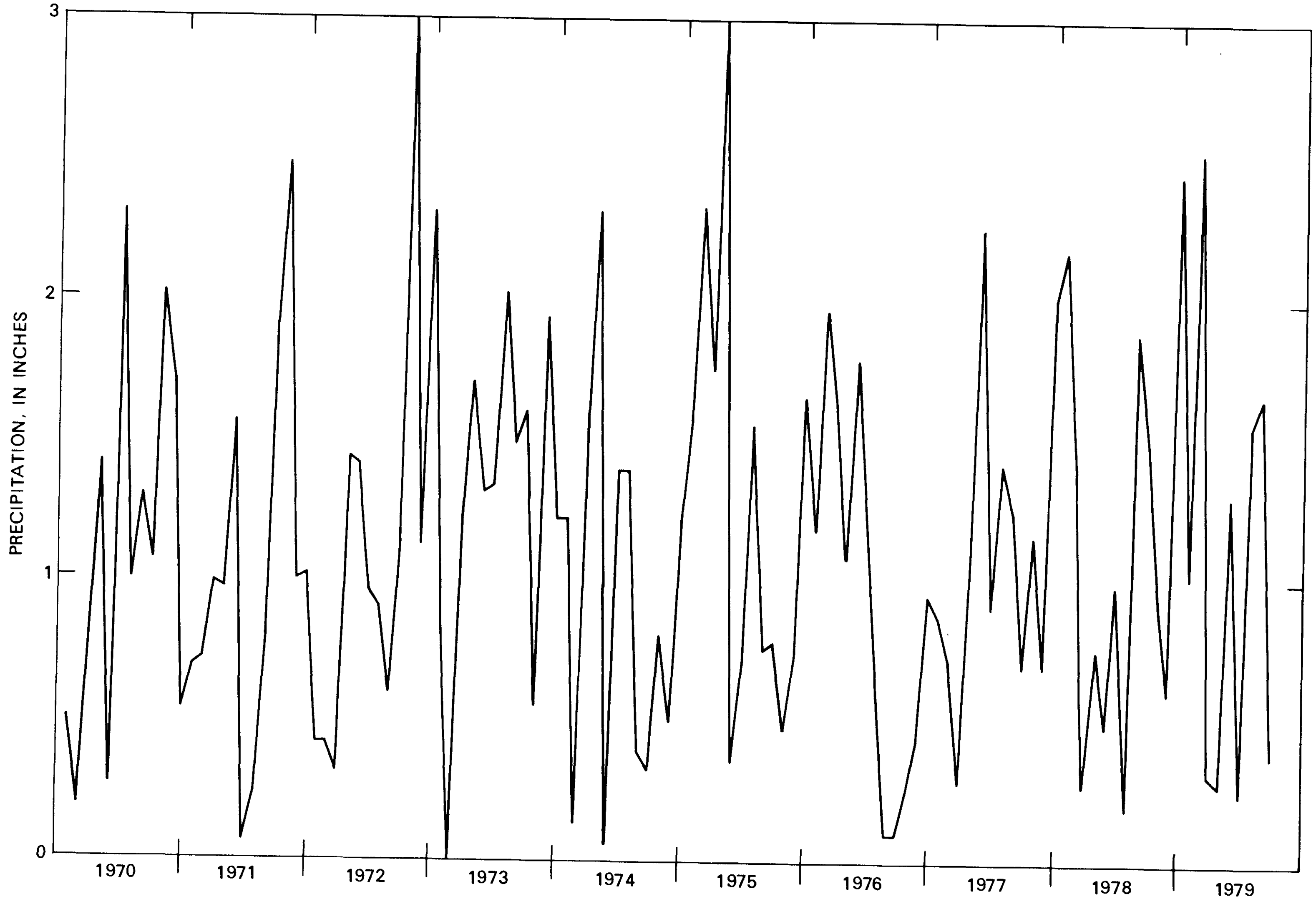

Figure 2.--Monthly precipitation at the Little Hills Game Experiment Station.

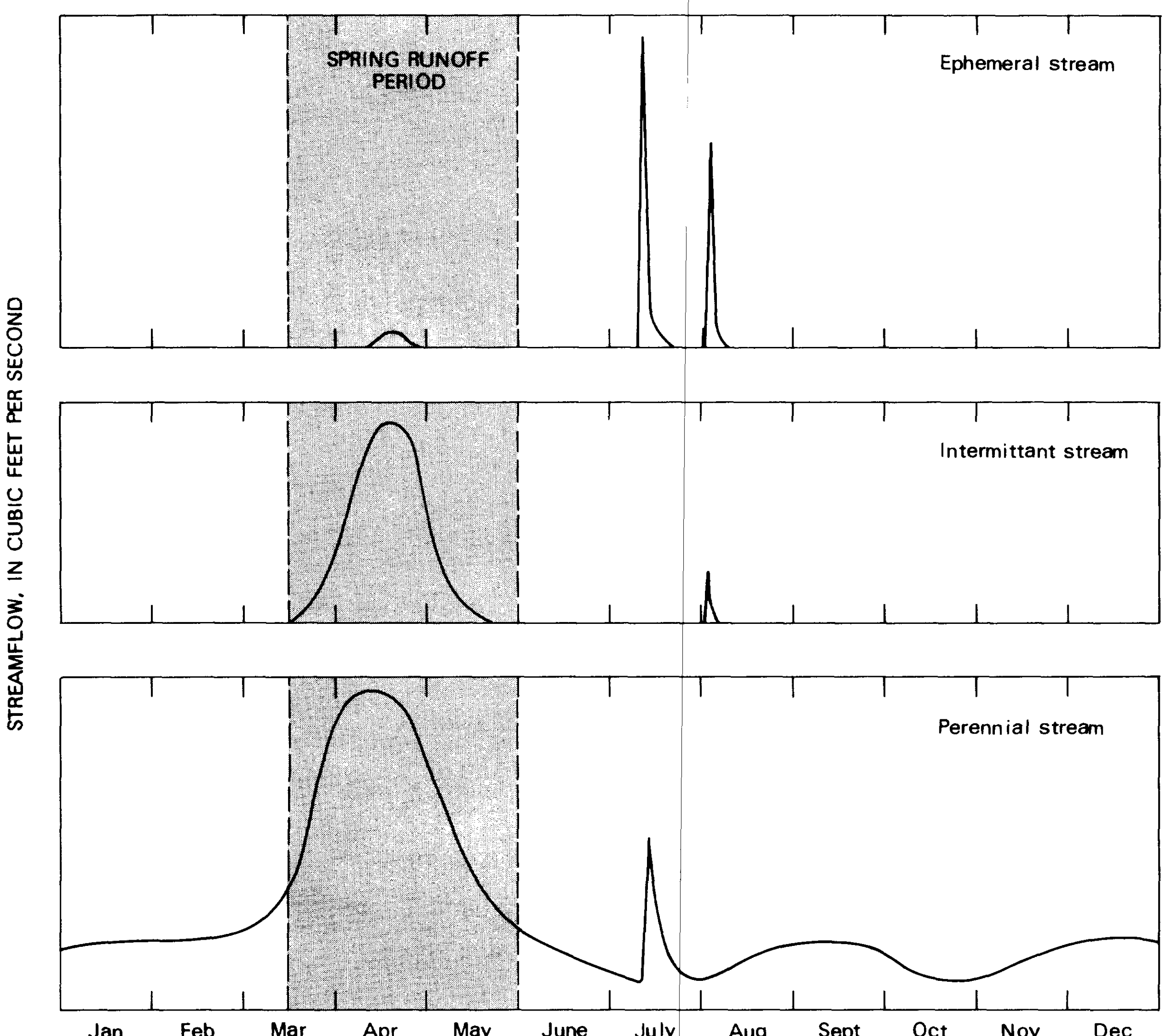

Figure 3.-- Typical monthly distribution of water discharge in streams in the Piceance basin.

Table 1.--*Peak discharges for period of record on ephemeral streams in the Piceance basin*

U.S. Geological Survey station No.	Station No. shown in figure 1	Peak of record (cubic feet per second)	Date (month/day/year)
09306015	2	3.2	02/09/76
09306025	4	1.5	02/19/80
09306028	5	38	09/03/77
09306033	6	7	07/09/75
09306036	7	59	09/03/77
09306039	8	53	09/03/77
09306042	9	384	09/03/77
09306050	10	11	07/29/78
09306052	11	6	07/29/78
09306202	16	11	09/11/77
09306203	17	54	07/24/77
09306237	21	202	07/23/77
09306241	23	139	09/07/81
09306246	26	20	03/01/76
09306248	27	62	07/23/77
09306250	28	12	02/28/76

Land Use

Prior to 1978, land use within the Piceance basin was limited to cattle ranching, agriculture, oil and gas exploration, and development. Known deposits of oil shale in the Green River Formation exceed 1 trillion barrels of crude oil. Development of this natural resource began about January 1, 1978. At that time, development began on the two 5,000-acre Federal oil-shale lease tracts, C-a and C-b (fig. 1). Site development has proceeded rapidly, and extensive local development has denuded some land areas of vegetation, exposing additional surfaces to erosion. At the present time, oil-shale development within the Piceance basin is limited to the two Federal lease tracts. Future development on these and other Federal and private lands may include extensive surface mining and retorting of oil shale.

SAMPLING PROGRAM

Suspended-sediment data were collected at 29 streamflow-gaging stations in the basin (fig. 1 and table 2). Mean daily sediment discharges were computed for each station during the period of record.

Table 2.--*Number and name of sediment-collection stations*

Station No. in figure 1	U.S. Geological Survey station No.	Station name
1	09306007	Piceance Creek below Rio Blanco.
2	09306015	Middle Fork Stewart Gulch near Rio Blanco.
3	09306022	Stewart Gulch above West Fork, near Rio Blanco.
4	09306025	West Fork Stewart Gulch near Rio Blanco.
5	09306028	West Fork Stewart Gulch at mouth, near Rio Blanco.
6	09306033	Sorghum Gulch near Rio Blanco.
7	09306036	Sorghum Gulch at mouth, near Rio Blanco.
8	09306039	Cottonwood Gulch near Rio Blanco.
9	09306042	Piceance Creek tributary near Rio Blanco.
10	09306050	Scandard Gulch near Rio Blanco.
11	09306052	Scandard Gulch at mouth, near Rio Blanco.
12	09306058	Willow Creek near Rio Blanco.
13	09306061	Piceance Creek above Hunter Creek, near Rio Blanco.
14	09306175	Black Sulphur Creek near Rio Blanco.
15	09306200	Piceance Creek below Ryan Gulch, near Rio Blanco.
16	09306202	Horse Draw near Rangely.
17	09306203	Horse Draw at mouth, near Rangely.
18	09306222	Piceance Creek at White River.
19	09306230	Stake Springs Draw near Rangely.
20	09306235	Corral Gulch below Water Gulch, near Rangely.
21	09306237	Dry Fork near Rangely.
22	09306240	Box Elder Gulch near Rangely.
23	09306241	Box Elder Gulch tributary near Rangely.
24	09306242	Corral Gulch near Rangely.
25	09306244	Corral Gulch at 84 Ranch, near Rangely.
26	09306246	Yellow Creek tributary near 84 Ranch, near Rangely.
27	09306248	Duck Creek at upper station, near 84 Ranch, near Rangely.
28	09306250	Duck Creek near 84 Ranch, near Rangely.
29	09306255	Yellow Creek near White River, near Rangely.

Because of the nature of the sediment data-collection program and the inaccessibility of many of the installations, automatic pumping samplers (PS-69) with fixed intakes were used to collect daily sediment samples. Periodic cross-section samples were taken to determine a relation between the single-point sample and the average stream concentration determined by the cross-section sample. All samples were collected in accordance with established sediment-sampling procedures used by the U.S. Geological Survey (Guy and Norman, 1970).

The PS-69 sampler is better suited for perennial streams where it is operated year round. On ephemeral and intermittent streams the effectiveness of the PS-69 sampler is limited, because breakdowns commonly occur as a result of infrequent operation.

WATER-SEDIMENT DISCHARGE RELATIONS

Relations between suspended-sediment discharge and water discharge are usually presented in the form of a logarithmic plot of suspended-sediment discharge against water discharge with a least-squares regression employed to fit a straight line through the scatter of points. Theoretically, only two data points are needed to define such a curve, but the data are usually so variable that confidence can only be obtained if the curve is defined by at least several data points. In addition, in recent years the use of suspended-sediment discharge instead of suspended-sediment concentration has been criticized because water discharge is used to calculate sediment discharge; this causes the high correlation between sediment and water discharge. However, the suspended-sediment discharge versus water-discharge relations are very useful for extending records and computing annual suspended-sediment discharge. Therefore, for this study, suspended-sediment discharge-water discharge relations are presented, but only at stations having at least six data points and a correlation coefficient for the suspended concentration-water discharge relation that was significantly different from 0 at the 95-percent confidence level. In other words, only those stations that had a defined suspended-sediment concentration-water discharge relation were considered for the determination of a suspended-sediment discharge-water discharge relation. Of the 29 streamflow-gaging stations listed in table 2, only 14 met these criteria.

Data on the log-transformed regression equations representing instantaneous suspended-sediment discharge as a function of water discharge at the 14 stations are shown in table 3. The curves defined by these regression equations are shown for a common range of water discharge so they can be compared (fig. 4). This illustration shows at which stations the suspended-sediment discharge is highest for a given value of water discharge and also the variability within the basin. If these relations are used for predictive purposes, care should be taken to limit their use to the range of water discharge for which they were developed (table 3).

Other variables besides water discharge influence the level of sediment discharge. These other variables could be basin characteristics or seasonal and climatic factors. These factors are investigated in the section on "Regionalization Analysis."

Table 3.--*Statistics and coefficients for regressions of instantaneous suspended-sediment discharge versus instantaneous water discharge at stations in the Piceance and Yellow Creeks drainage basin*

Station No.	Average standard error, in percent	Coefficients for equation of formula: Log Q_s=Log a+b Log Q		Range of water discharge	
		a	b	Minimum	Maximum
09306007	160	0.03	2.15	0.600	154.0
09306028	71.0	1.12	1.19	.012	11.49
09306033	224	121	2.47	.000	134.6
09306058	144	.23	1.68	.004	22.04
09306061	135	.01	2.42	.049	1,400
09306175	156	.06	2.10	.014	1,084
09306200	117	.02	2.23	.182	2,524
09306222	153	.03	2.03	.080	2,465
09306240	346	1.37	1.66	.000	52.78
09306241	121	7.20	1.23	.011	203.9
09306242	371	.44	2.35	.003	1,131
09306244	287	1.42	1.90	.000	347.3
09306246	25.7	8.98	1.72	25.59	698.0
09306255	182	.27	2.06	.002	28,560

If, due to budget or other constraints, the sediment-data collection had to be reduced, the instantaneous relations could be used for prediction of long-term sediment yields. If there is a reduction in sediment-data collection, additional samples need to be collected during extreme high-discharge events to establish better relations between water and sediment discharge. Also, data need to be collected on both the rising and falling limbs of the hydrograph in order to determine if any hysteresis exists. Data also should be collected during different seasons in order to delineate seasonality effects. This type of data-collection program may help to improve the standard errors shown in table 3.

REGIONALIZATION ANALYSIS

Regionalization is a technique for relating hydrologic parameters to climatic and physiographic characteristics of a drainage basin. Regional relations generally are expressed in a multiple-regression model and may be used to estimate (1) Regional hydrologic parameters, (2) hydrologic parameters at ungaged sites, and (3) hydrologic parameters at gaged sites whose standard errors are less than those provided by the observed time series (Matalas and Benson, 1961; Matalas and Gilroy, 1968; Thomas and Benson, 1970; and Moss and Karlinger, 1974). This study utilizes multiple-linear-regression techniques to define spatial and time variations in sediment discharge as a function of climatic, physical, and land-use characteristics of the basin.

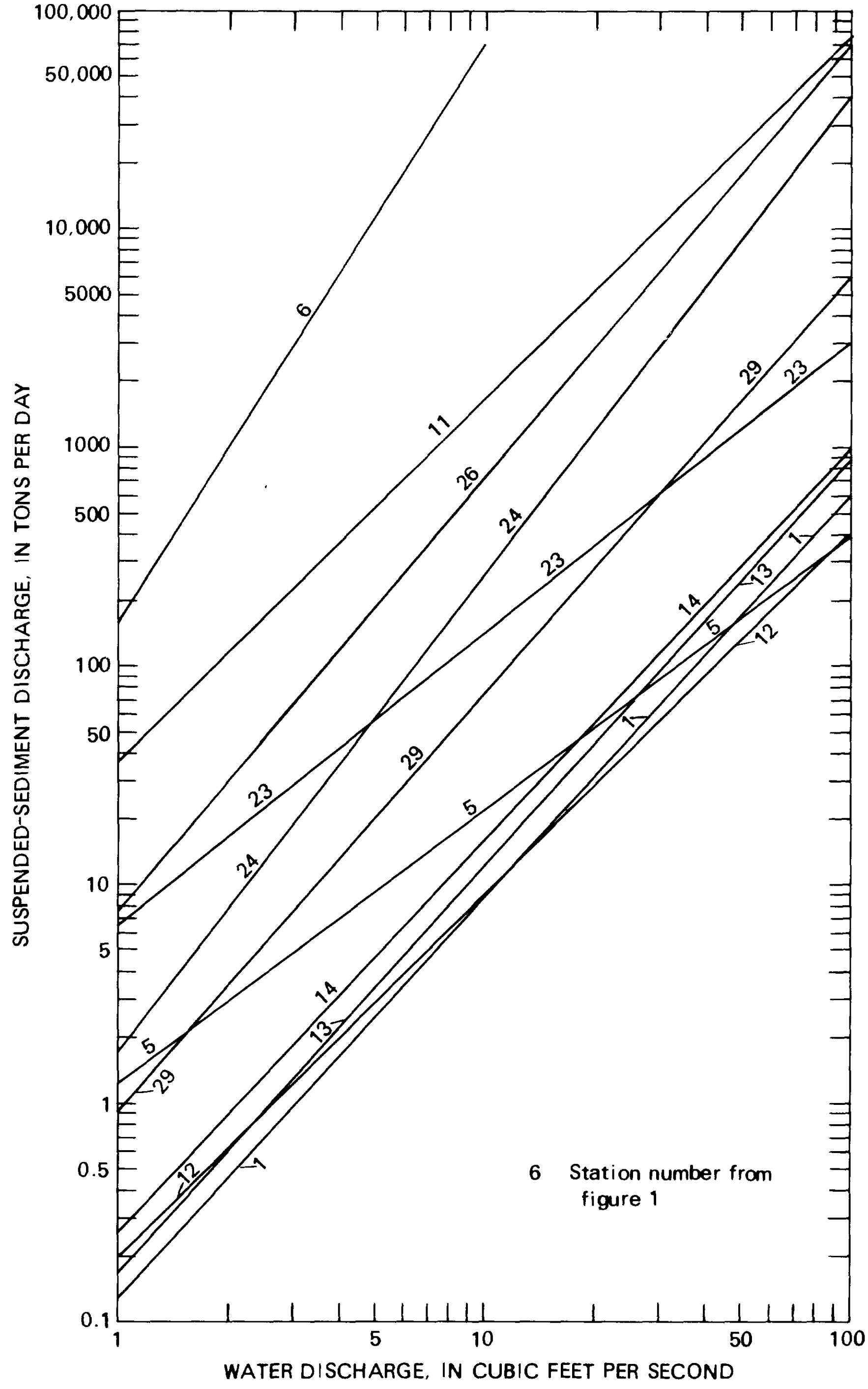

Figure 4.--Relations between suspended-sediment discharge and water discharge at streamflow-gaging stations in the Piceance and Yellow Creeks drainage basins.

In most regression analyses of streamflow, basin characteristics and sediment transport logarithmic transformations of all variables are used. The reasons for transforming the data are: (1) To normalize the variables and residuals, (2) to give the residuals a constant variance about the regression line, as required in classical regression analysis, and (3) to obtain a linear-regression model. A logarithmic transformation results in a relation of the form:

$$\log Y = \log B_0 + B_1 \log X_1 + B_2 \log X_2 + B_3 \log X_3 \ldots . B_n \log X_n \tag{1}$$

or taking antilogs,

$$Y = B_0 X_1^{B_1} X_2^{B_2} X_3^{B_3} \ldots . X_n^{B_n} \tag{2}$$

where Y (dependent variable) is sediment discharge, X's (independent variables) are physiographic, water discharge, and climatic characteristics that describe the basin upstream from the site for which the estimate is being made, B's are coefficients determined by the regression analysis based on information collected at the gaged sites, and n is the number of basin characteristics. The resulting standard error of estimate for regressions of such transformed variables is in log units, but it can be converted to a percentage by the formula (Gary Tasker, written commun., 1978),

$$(SE)_p = (-1 + e^{SE^2})^{\frac{1}{2}} \tag{3}$$

where $(SE)_p$ is the standard error in percent and SE is the standard error in log units (base e).

A network-analysis procedure described by Moss and Karlinger (1974) analyzes mean monthly and mean annual values. An assumption of this analysis is that the design variables are stationary; however, because of the short sediment record of the Piceance basin, the required stationarity conditions cannot be verified. To better determine potential nonstationarity of mean monthly and mean annual values with respect to mining, the regionalization analysis was performed in two stages. The monthly mean values were examined in the first stage. This data base has an adequate number of observations to separate the effects of mining. Added benefits of using monthly means were the ability to inspect seasonality effects on sediment discharge and to examine differences between stations downstream from the mining versus those upstream from the mining. The second stage of regional analysis was guided by results of the first stage. This second stage will be discussed further in the section on "Regional Equations for Monthly and Annual Sediment Discharge."

Selection of Variables

The dependent variable used in this analysis was monthly mean suspended-sediment discharge (Q_s), whereas the independent variables considered were monthly mean water discharge, drainage area, main-channel length, main-channel slope, drainage density, basin length, average basin slope, percent of basin having slopes greater than 20 percent, average basin elevation, forest cover, monthly mean precipitation, mean annual precipitation, and the maximum 24-hour rainfall having a recurrence interval of 2 years.

The period of sediment-discharge record, basin characteristics, and precipitation data are listed in table 4. The authors recognize that other meaningful independent variables, such as indices for soil and mineral composition, might prove to be useful for the suspended-sediment discharge regression analysis; however, because quantitative information is unavailable for such variables and because of the preliminary nature of the study, only the independent variables described above were used.

Analysis

A stepwise regression procedure was applied to eliminate those variables that were not significant at the 95-percent level (SAS Institute, 1979)[1]. The basin characteristics found to be significant and used in the final model for monthly mean analysis were: (1) Drainage area (*DA*), (2) basin length (*BL*), (3) maximum 24-hour rainfall with a recurrence interval of 2 years (*I*), (4) mean annual precipitation (*MAP*), (5) monthly mean precipitation at the Little Hills precipitation station (*PLH*), and (6) monthly mean water discharge (*Q*) at each station for the period of record. This resulted in a log-linear regression model in which:

$$Q_s = f(DA,\ BL,\ I,\ MAP,\ PLH,\ Q); \qquad (4)$$

where f ( ) means "a function of."

In order to evaluate differences due to mining and seasonality, an analysis utilizing dummy variables was included in the first regionalization analysis. The term "dummy" simply means that the values (usually 0 or 1) taken on by such variables were not measured but only indicate a category of interest, for example, whether the data were collected before or after mining. It is through the use of dummy variables that regression analysis assumes a broad range of application. In particular, the use of dummy variables allows one to employ regression analysis to produce the same information that is obtained by such procedures as analysis of variance and analysis of covariance. The use of dummy variable analysis also allows one to compare regression equations for several categories by use of a single multiple-regression model.

Dummy variables were included in the regression model to evaluate differences in suspended-sediment discharge before and after mining, differences between areas downstream from mining and those upstream from mining, and differences between seasons. The dummy variables (*Z*) assigned for each monthly observation are as follows:

$Z1=0$ indicates before mining (before January 1978),
$Z1=1$ indicates after mining (after and including January 1978),
$Z2=0$ indicates sites downstream from mining,
$Z2=1$ indicates sites upstream from mining,
$Z3=0$ indicates season 1, February through May, and
$Z3=1$ indicates season 2, June through January.

[1]The use of the brand name in this report is for identification purposes only and does not imply endorsement by the U.S. Geological Survey.

Table 4.--*Summary of the basin characteristics of streams in the Piceance and Yellow Creeks drainage basin*

[*=upstream from mine development; **=downstream from mine development]

U.S. Geological Survey station No.	Station No. in figure 1	Period of sediment-discharge record	Drainage area, in square miles	Main channel length, in miles	Main channel slope, in feet per foot	Drainage density, in miles per square mile	Basin length, in miles	Average basin slope (percent)	Percent of basin with slopes greater than 20 percent	Average basin elevation, in feet	Percent forest cover	Precipitation, in inches: Mean annual	Precipitation, in inches: 2-year 24-hour
09306007*	1	1974-80	177	25.2	0.012	1.63	16.6	36	70	7,327	82.5	23.9	1.29
09306015*	2	1974-76; 1978-80	24	10.8	.022	1.00	9.7	36	71	7,564	83.7	22.0	1.23
09306022*	3	1974-80	44	13.4	.020	1.17	11.3	34	69	7,485	88.5	22.0	1.23
09306025*	4	1974-76; 1978-80	14.2	10.0	.022	1.46	10.1	22	40	7,709	82.0	21.4	1.21
09306028**	5	1974-76	15.7	11.0	.022	1.38	11.9	20	36	7,620	90.5	21.4	1.20
09306033*	6	1974-80	1.22	3.0	.066	1.64	2.6	13	0	7,040	75.0	19.0	1.17
09306036**	7	1974-80	3.62	4.6	.040	1.79	5.2	21	33	6,947	85.0	18.0	1.17
09306039**	8	1974-80	1.20	2.0	.056	1.67	2.3	15	30	6,560	85.0	16.0	1.17
09306042**	9	1974-80	1.06	2.0	.051	2.59	1.9	24	50	6,680	70.0	16.0	1.17
09306050*	10	1974-76; 1978-80	6.61	5.7	.039	1.24	6.6	18	20	7,325	75.0	19.0	1.20
09306052**	11	1974-80	7.97	7.4	.037	1.24	7.9	19	45	7,166	75.0	19.0	1.20
09306058**	12	1974-80	48.4	15.0	.016	1.41	19.8	32	63	7,530	86.3	22.0	1.24
09306061**	13	1974-80	309	30.7	.011	1.53	20.9	34	66	7,340	85.0	22.4	1.26
09306175*	14	1975-80	103	20.7	.020	1.43	17.6	16	28	7,241	70.3	21.8	1.22
09306200**	15	1972-80	506	39.0	.009	1.74	24.2	28	54	7,262	79.5	21.8	1.24
09306202*	16	1977-80	1.47	1.2	.104	.81	1.0	18	25	6,640	85.0	15.0	1.11
09306203**	17	1977-80	2.87	1.4	.086	.49	2.2	18	25	6,480	75.0	14.5	1.15
09306222**	18	1974-80	630	57.0	.006	1.74	28.4	26	49	7,208	79.1	20.5	1.21
09306230*	19	1974-80	26.1	13.3	.024	1.92	11.0	22	40	7,522	79.2	19.8	1.22
09306235*	20	1974-80	8.61	4.0	.045	2.53	4.1	32	63	7,755	75.0	20.5	1.23
09306237*	21	1974-80	2.74	4.4	.037	2.94	3.4	26	31	7,410	75.0	21.0	1.23
09306240*	22	1975-80	9.21	6.6	.044	2.93	7.1	28	61	7,513	75.0	20.5	1.23
09306241**	23	1974-80	2.39	3.9	.031	1.82	3.6	21	30	7,055	75.0	21.5	1.23
09306242**	24	1975-80	31.6	8.4	.034	1.94	7.3	27	54	7,324	75.0	21.0	1.23
09306244**	25	1975-77	37.8	11.2	.031	1.99	9.9	22	45	7,220	75.0	20.0	1.24
09306246*	26	1975-77	5.53	7.3	.022	1.73	6.9	9	7	6,731	78.0	19.0	1.22
09306218*	27	1975-77	39.1	8.2	.039	2.05	10.0	25	45	7,342	75.0	19.5	1.22
09306250*	28	1975-77	50.0	13.1	.026	2.33	12.3	22	38	7,080	82.5	19.4	1.21
09306255**	29	1974-80	262	30.0	.010	1.73	22.2	21	41	6,704	73.1	17.2	1.15

The seasons were selected in order to seperate the snowmelt-runoff period from the months of thunderstorms and base flow. This combination yielded the best results in the analysis. There are actually eight regression equations, one for each combination of values taken on by Z1, Z2, and Z3. By including these dummy variables in the model and utilizing the student's t statistic at the 95-percent confidence level, one can determine whether there is a significant difference between any two of the eight equations. The results of the analysis are shown in table 5.

Whether a shift or change in trend in the regression equation has occurred between any two of the eight equations is shown in table 5. An example of shift and trend change is shown in figure 5. A shift is a significant increase or decrease in the intercept, whereas a change in trend is an increase or decrease in the slope of the regression line. Therefore in table 5, a plus sign indicates a significant change in the intercept or slope of the lines being compared while a minus sign indicates no significant change between the intercept or slope of the regression lines being compared at the 95-percent level.

Table 5.--*Indicators of significant change in monthly mean suspended-sediment discharge with respect to the independent variables*

[+ indicates a significant difference in the lines at the 95-percent confidence level; - indicates no significant difference in the lines at the 95-percent confidence level]

Equations compared: Fixed factors	Equations compared: Comparative factors	Regression constant (indicator of direction of shift in regression line)	Water-discharge slope coefficient (indicator of change in trend)
Season 1; premining-----------	Upstream/downstream stations	+	-
Season 1; postmining----------	Upstream/downstream stations	-	-
Season 2; premining-----------	Upstream/downstream stations	-	-
Season 2; postmining----------	Upstream/downstream stations	+	+
Season 1; upstream stations----	Premining/postmining--------	-	+
Season 1; downstream stations--	Premining/postmining--------	-	-
Season 2; upstream stations----	Premining/postmining--------	-	-
Season 2; downstream stations--	Premining/postmining--------	+	+
Premining; upstream stations---	Season 1/season 2-----------	-	-
Postmining; upstream stations--	Season 1/season 2-----------	-	+
Premining; downstream stations-	Season 1/season 2-----------	-	-
Postmining; downstream stations	Season 1/season 2-----------	-	-

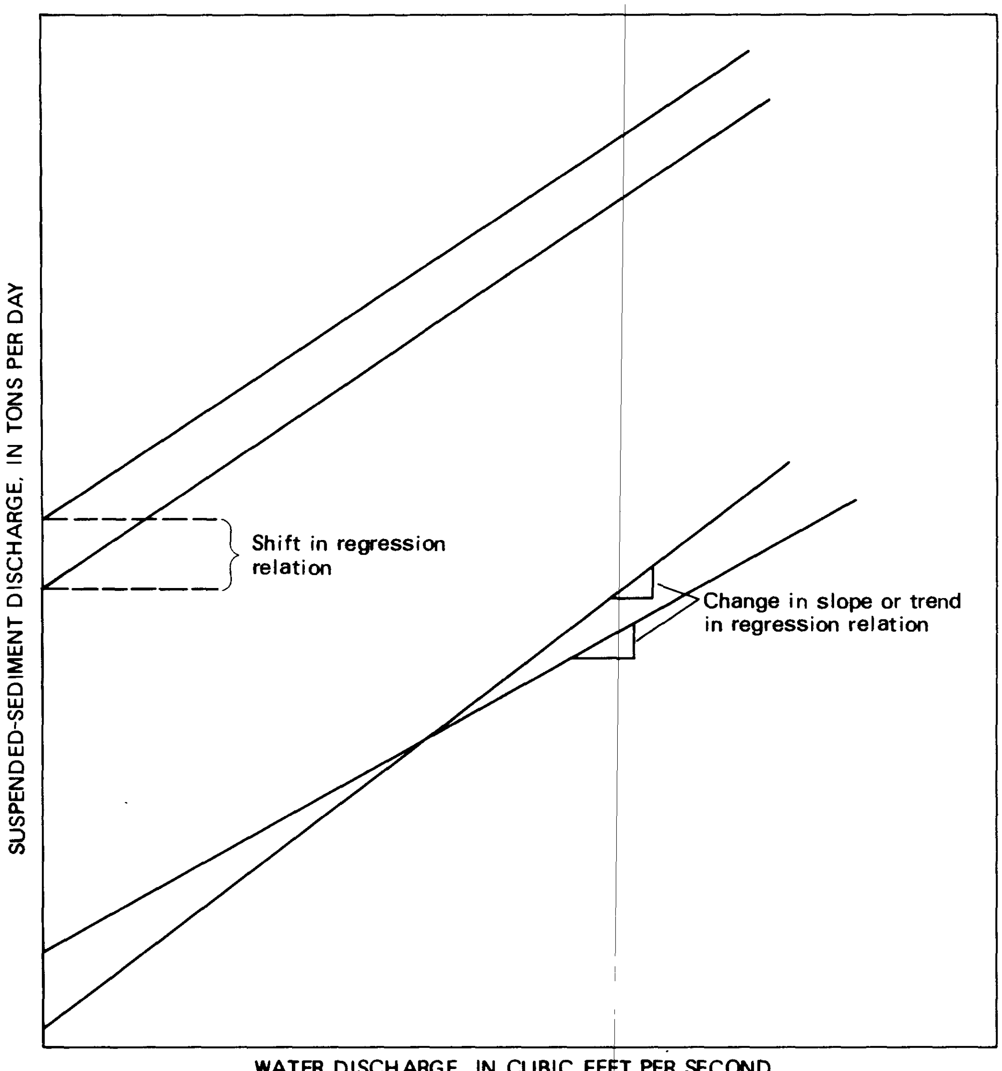

Figure 5.--Example of shift and trend change in linear-regression equations.

Changes due to mining can be detected not only by shifts in the entire relationship, but also by increases or decreases in the slope of the regression line. It is important to note that the analysis is made primarily to determine these changes and secondarily to estimate the particular flow variable at site if the regressions are adequate. One can obtain a graphical representation of suspended-sediment discharge versus water discharge for the various combinations of the dummy variables by fixing the other independent variables at their mean values. These results are shown in figures 6 and 7.

Changes in the value of the intercept compared with significant changes in the coefficients of the independent variables. Because in many cases the shifts in intercept were countered by increases in the slope coefficient, no conclusion could be drawn concerning an absolute increase or decrease in sediment yield. For example, during season 1 (February through May) the intercept of the postmining regression line representing the station upstream shifted downwards, but at the same time the slope coefficient of the water discharge increased. This indicated less sediment discharge for flows less than about 9 ft^3/s at stations upstream from mining, but more sediment discharge for water discharges greater than 9 ft^3/s (fig. 6). Although change in the sediment discharge can be seen in figures 6 and 7, this change cannot be attributed to mining because the change occurs both upstream and downstream of the mining.

In general, there is considerable variability in the sediment loads in the basin, as shown in table 5. Because the period of record is so short, it is hard to determine what, if anything, besides natural phenomena is causing the changes in the suspended-sediment load. To investigate further the variability of the sediment load in the basin, a separate regression analysis was performed using the monthly means, but excluding water discharge as an independent variable. This regression analysis, when compared with the previous analysis, showed that a high percentage of the variability in sediment discharge is due to variability in the water discharge. The importance of water discharge in the analysis indicates that any network modifications should concentrate on obtaining an accurate water discharge and sediment record and maintaining or developing a good sediment-water discharge relation. These regressions also show considerable variability in the discharges of season 2 (June through January). This is because this season includes the large summer thunderstorms.

REGIONAL EQUATIONS FOR MONTHLY AND ANNUAL SEDIMENT DISCHARGE

Statistical analysis was performed to determine where and how much data need to be collected at the selected sites. To fully answer these questions, the economic use of the data must be defined such that benefits can be maximized; however until such uses can be defined and adequate network-design procedures become available, a surrogate measure of the adequacy of the network lies in the accuracy of the sample statistics, such as those presented in previous sections. As more data are collected, changes in these statistics will be noted and the marginal value of the additional data can be evaluated. Similarly, for network reduction, changes in sample statistics as a result of these reductions also can be studied.

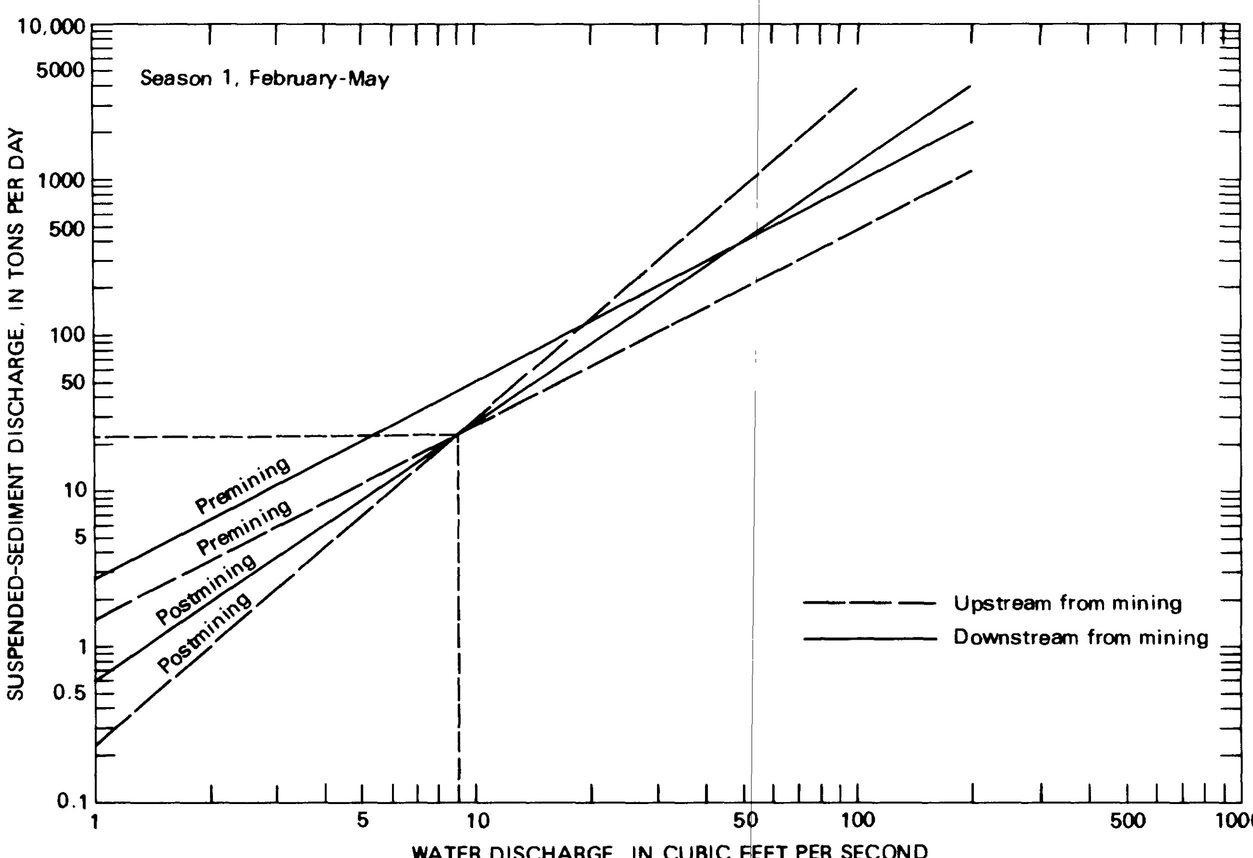

Figure 6.--Relation between suspended-sediment discharge and water discharge during season 1 based on monthly mean multiple-regression analysis.

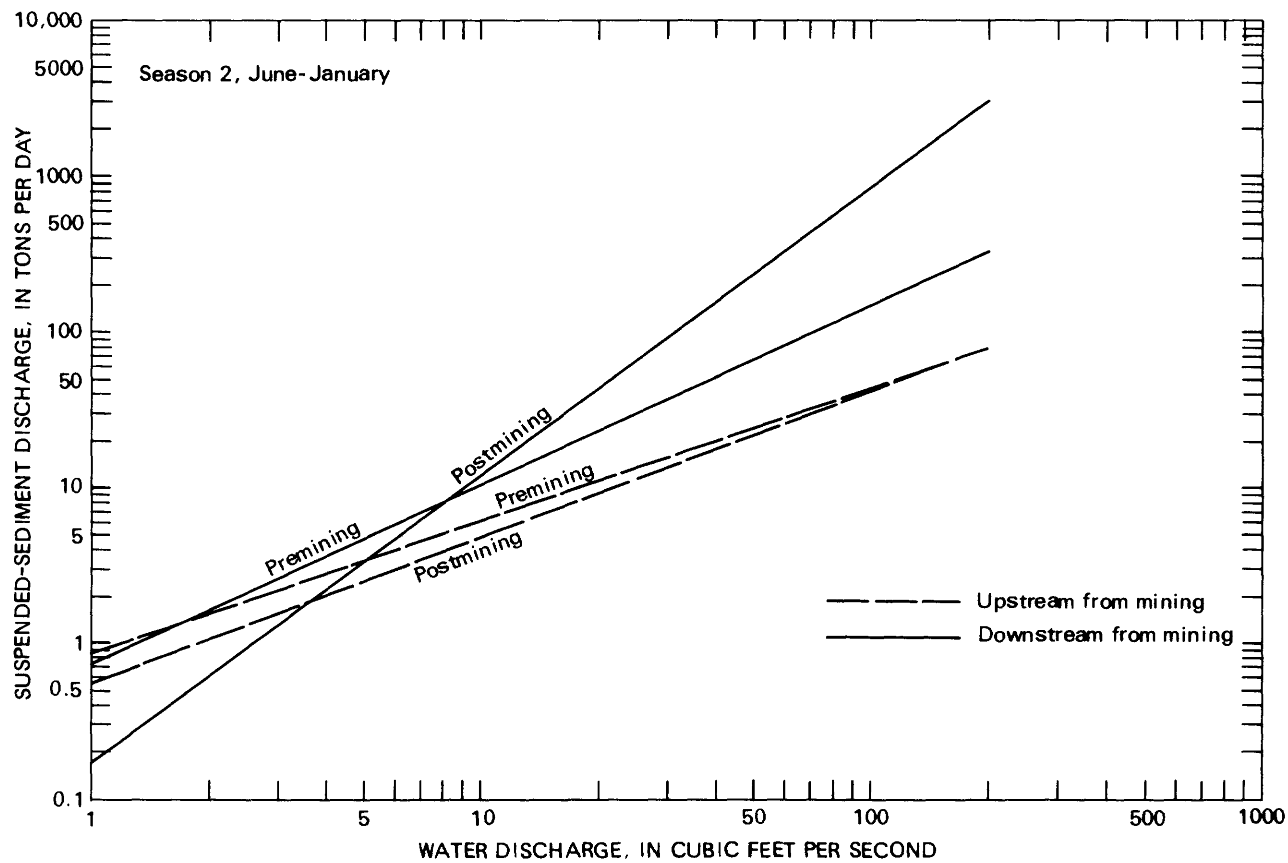

Figure 7.--Relation between suspended-sediment discharge and water discharge during season 2 based on monthly mean multiple-regression analysis.

The results of the first stage of the multiple-regression analysis (which utilized monthly mean data) were used to determine if there was a need to include premining and postmining and upstream and downstream location variables in the network analysis to account for nonstationarity. The network analysis utilized mean monthly and mean annual data as recommended by Moss and Karlinger (1974). It was found that it was necessary to account for both premining and postmining conditions and for the location of streamflow-gaging stations either upstream or downstream from the mining; however, a stepwise regression analysis of the mean monthly and mean annual values indicated that the upstream or downstream dummy variable was not significant in the regression. The insignificance of the upstream and downstream location variable is due to the averaging process used in the stepwise regression, which smooths or masks any of the nonstationarity variability indicated in the first stage of the regional analysis. If indeed there is nonstationarity due to mining, it can only be recognized using several more years of postmining data.

The final regression model used for the mean monthly and mean annual data was based on the stepwise regression results and included only drainage area and the dummy variable for premining and postmining conditions. The regressions were run for each monthly and annual value using the same statistical packages used in the first stage and assuming stationarity. The 13 equations and standard errors that resulted from this analysis are presented in table 6. Only the postmining relations are presented since change has occurred between the two time periods.

In addition to the sediment-discharge equations, mean monthly and mean annual water discharge were used as dependent variables, and regression analyses were run for comparative purposes using the same set of independent variables. Because of the preliminary nature of these regressions, any predictions using these results (table 7) should be made with caution.

The use of site-specific analysis for predictive purposes or determination of data needs requires a knowledge of the effects of development in the basin. An example of streamflow-gaging station data that show different regression relations corresponding to premining and postmining conditions is shown in figure 8. For those stations at which a change has occurred, one should concentrate on improving the postmining record for predictive purposes. The premining relation will no longer apply to the existing postmining conditions. The regression lines show the same adjustment from premining to postmining conditions as that shown in the regional analysis (fig. 8). This reinforcement is indicative of the data needs for better definition of the postdevelopment changes.

SEDIMENT YIELD

Sediment yield is defined as the sediment outflow from a drainage basin measurable at a cross section of reference and in a specified period of time. The sediment yields for six selected stations in the Piceance and Yellow Creeks drainage basin are shown in table 8 and are based on daily sediment samples collected at the mouth of each drainage basin. These stations were selected to compare sediment

Table 6.--*Results of mean monthly and mean annual suspended-sediment discharge regression analysis for the Piceance and Yellow Creeks drainage basin*

Month	Average standard error, in percent	Coefficients for the equation Log Q_S=Log a+b log DA	
		a	*b*
January	87	-0.68	0.44
February	142	-.50	.60
March	115	-.74	.70
April	217	-.36	.76
May	328	-.19	.88
June	153	-.74	.66
July	98	-.14	.35
August	108	-.38	.50
September	412	-.80	.60
October	92	.19	.16
November	90	-.66	.40
December	90	-.68	.39
Annual	117	-.98	.86

Table 7.--*Results of mean monthly and mean annual water-discharge regression analysis for the Piceance and Yellow Creeks drainage basin*

Month	Average standard error, in percent	Coefficients for the equation Log Q=Log a+b log DA	
		a	*b*
January	84	0.64	0.49
February	71	.74	.55
March	70	.86	.59
April	85	-.74	.63
May	110	-.58	.69
June	73	-.48	.54
July	61	-.19	.41
August	13	-.47	.51
September	62	-.45	.48
October	58	-.37	.37
November	68	-.64	.47
December	82	-.62	.45
Annual	74	-.76	.57

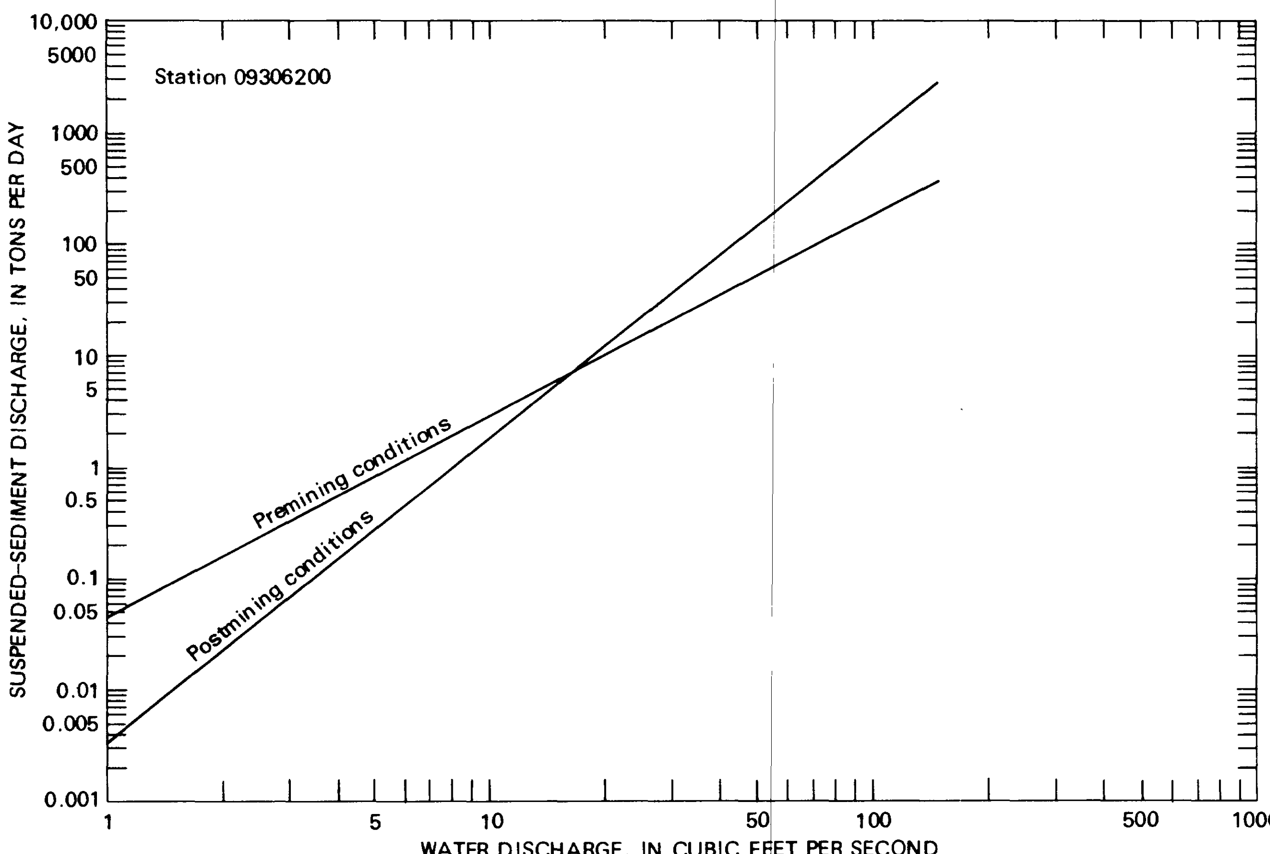

Figure 8.--Relation between instantaneous suspended-sediment discharge and instantaneous water discharge at station 09306200, Piceance Creek below Ryan Gulch.

yields at the stations upstream from the mining development with those downstream from the development and also to show the sediment yields before mining began and after mining began.

The sediment yields increased following the beginning of mining development; however, the sediment yields also increased at those stations upstream from the development. As previously found in the regional analysis, the changes occur for both the stations upstream and downstream from the development so it is difficult to say that mining caused the increased sediment yield. The variability within the basin from year to year and from station to station also is shown in table 8. For example, Yellow Creek at White River City had a 1978 water-year sediment yield higher than all other years of record combined. This would indicate that a longer period of record is needed to better estimate the effect of the infrequent events that cause most of the sediment erosion within the basin.

CONCLUSIONS

This network analysis is preliminary and describes changes that may have occurred after mining began. It was found that the suspended-sediment load in the region has changed, but there is no conclusive evidence indicating mining as the cause. This analysis was performed using standard multiple regression of monthly mean loads versus basin parameters and dummy variables. Because of the short record available, monthly mean loads were used to increase the data base. The dummy variables were included to indicate differences, if any, between seasonal loads, between sediment loads at streamflow-gaging stations upstream from mining and those downstream from mining, and between premining and postmining sediment loads.

An analysis of the mean monthly and mean annual data also was performed by using the results of the monthly mean analysis and by assuming that the sediment- and water-discharge data were stationary. Stepwise regression analysis indicated drainage area was the only significant independent variable. The results are preliminary and suggest further data collection is needed. As a result of the high variability of the data used in the regressions, it is not recommended that the regressions be used for predictive purposes until a larger data base can be obtained. The predictions are valid only for specific sites unaffected by development.

The statistical approach presented consists of exhaustive multiple regression analyses of existing data. The hydrologic analysis is based on knowledge of the processes which control suspended-sediment load, and the methodology could be applied to any region.

Sediment samples are needed primarily during peak-flow events to better define the suspended-sediment water-discharge relations. The nonstationarity of the water discharge influenced the results of the suspended-sediment analysis. Additional data are required to more accurately define the trends in water discharge in the region.

Table 8.--*Sediment yield at selected sites in the Piceance and Yellow Creeks drainage basin*

Station No. and name	Sediment yield, in tons per square mile									
								Average		
	1974	1975	1976	1977	1978	1979	1980	1974-80	1974-77	1978-80
09306007 Piceance Creek below Rio Blanco-------	46.9	115	17.9	32	70.5	160	147	84	53	126
09306200 Piceance Creek below Ryan Gulch, near Rio Blanco-------------	19.3	31.8	26.5	17.2	28.1	80.2	-----	34	24	54
09306222 Piceance Creek at White River City----	13.8	35.1	44.6	6.54	36.1	95.5	89	46	25	74
09306235 Corral Gulch below Water Gulch, near Rangely-----------	-----	5.47	8.22	1.92	11.8	85.8	47.4	27	5.2	48
09306242 Corral Gulch near Rangely-----------	-----	34.1	32.8	54.6	159	119	95.8	83	41	125
09306255 Yellow Creek at White River City-------	1.69	2.59	9.26	3.78	1,110	5.65	47.9	169	4.3	388

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