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WATER QUALITY CHARACTERISTICS OF THE HORSE CREEK WATERSHEDS IN NORTH CENTRAL IDAHO

by

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TABLE OF CONTENTS

List of Tables

List of Figures

List of Appendices

ABSTRACT

Principal component analysis was performed on a set of geomorphic descriptors for ten undisturbed forested watersheds in north central Idaho. This analysis provided a means of watershed classification and was an aid in the selection of geomorphic variables useful in explaining differences in sedimentation processes between watersheds and/or groups of watersheds. Total basin area and relief ratio were the two most useful descriptors in evaluating sedimentation differences.

Bedload transport rates and suspended sediment concentrations were monitored for three water years. Bedload transport and suspended sediment rating curves were developed for the individual watersheds using the following model: $\log_{10} Y = \beta_0 + \beta_1 \log_{10} X + \varepsilon$, where Y = bedload transport rate (lb/hr) or suspended sediment concentration (mg/l), X = stream discharge (ft^3/sec) and ε = error. This rating curve can be used to predict annual sediment yields and as a means of evaluating the effects of management activities on sedimentation processes.

Total annual sediment yields exhibit a great deal of annual variability largely due to annual differences in water yields, influenced by snowmelt volumes and snowmelt rates. Approximately 95% of the annual sediment production occurs during the snowmelt season. For these watersheds, having soils with relatively high proportions of silts and clays, sediment transported in suspension is the dominant process, accounting for 49-74% of the sediment production.

Organic content and particle size distribution were determined for the transported bedload sediment and the total sediment deposited in debris basins at the mouth of each watershed. Approximately 11 percent of the total deposited sediment was organic matter. The median diameter for the deposited sediment ranged from 0.59 mm to 2.61 mm.

Trap efficiencies for the debris basins were estimated. An average of 40 percent of the total sediment yield was deposited in these basins. This low trap efficiency was due to the fact that approximately 77 percent of the sediment transported in suspension was flushed through the debris basins.

The concentrations of dissolved chemicals in the Horse Creek streams were very low. The sulfate, calcium, magnesium, potassium and sodium concentrations and pH, specific conductivity, and alkalinity were inversely related to stream discharge. These dilution relationships were influenced by basin geomorphology. The lemniscate constant, a shape descriptor, and the relief ratio had the most pronounced effect on the water chemistry-stream discharge relationships.

The results of this study indicate that geomorphology is related to water chemistry and sedimentation processes and there is a potential for better areal extrapolation of research results by incorporation of certain geomorphologic parameters.

INTRODUCTION

During the past decades there has been a growing concern for the integrity of our Nation's waters. However, the recognition of the need for their protection has not been a recent development. The Organic Act of 1897 was one of the first pieces of legislation that acknowledged the importance of forested lands as a water source. It stated that:

> "No national forest shall be established, except to improve and protect the forest within the boundaries, or for the purpose of securing favorable conditions of water flows, and to furnish a continuous supply of timber for the use and necessities of citizens of the United States."

Recent legislation and policy have been directed towards the maintenance or improvement of water quality. The Federal Water Pollution Control Act Amendments of 1972 states that its objective "is to restore and maintain the chemical, physical and biological integrity of the nation's water." Under this act, the administrator of the Environmental Protection Agency is charged with developing a program for the identification and control of nonpoint pollution generated by silvicultural activities. The Environmental Protection Agency identifies sediment as the most important pollutant originating from silvicultural activities (U.S. Environmental Protection Agency 1973), having the potential to degrade water quality physically, chemically and biologically.

The State of Idaho, by adoption of the 1974 Idaho Forest Practices Act, recognizes the necessity for proper forest practices to protect its water resources. It states that it is the public policy of Idaho "to encourage forest practices...that maintain and enhance those benefits and resources (water)" and..."to protect and maintain the forest soil, air, water resource, wildlife, and aquatic habitat."

Managers of forested lands must understand natural processes that influence water quality and the probable consequences of proposed management activities. In response to this need the National Forest Systems branch of the US Forest Service established a network of Barometer Watersheds. The purpose of these watersheds was the collection of hydrometeorological data and research to assess the impact of management activities on the soil and water resource. In north central Idaho, the Meadow Creek Drainage was selected as the Barometer Watershed representative of the Northern Rocky Mountain Physiographic Province. This 243 square mile undisturbed drainage is representative of many of the Rocky Mountain forest lands west of the continental divide. It is situated on the border of the Idaho Batholith, which has special management problems due to highly erosive soils.

The Horse Creek Administrative-Research Project was conceived in 1965 as the first intensive phase of the Barometer Watershed plan. This Project was a joint endeavor between Region 1 - Nezperce National Forest and the Watershed Management Research Work Unit, Intermountain Forest and Range Experiment Station. The objective of the Horse Creek Project was "to assess the effects of a timber sale and road construction project incorporating alternative logging and road systems, by installing a network of instruments to monitor hydrologic parameters before, during, and after management activity, assessing impacts on the soil and water resource" (USDA, 1976).

This research effort involved the investigation of water quality processes in ten subwatersheds of the Main Fork of Horse Creek Watershed prior to any management activity. The objectives of the study were to:

1) describe and quantify the water quality processes on the ten subwatersheds and to

2) determine the influence of geomorphology, climate, and channel stability on these processes.

3) present a methodology to calibrate the water quality process for the purpose of determining the effects of further management.

This report will initially describe the geomorphic characteristics of the drainages and utilize principal component analysis to aid in selecting characteristics useful in explaining differences between the drainages. It is hypothesized that geomorphology influences the water quality processes of a drainage. The sections of this report dealing with the sedimentation and water chemistry processes will incorporate a discussion of the influence of geomorphology.

EXPERIMENTAL SITE

The Horse Creek Watersheds are located in the north central portion of the state within the Nezperce National Forest, approximately thirty-five air miles east of Grangeville, Idaho. Horse Creek, situated in the northern portion of the Meadow Creek Barometer Watershed, flows into Meadow Creek four miles above its confluence with the Selway River.

The Horse Creek study area is comprised of two major watersheds drained by the East Fork and Main Fork of Horse Creek (Figure 1). The East Fork Watershed is a control watershed which will remain in its present undisturbed state. The Main Fork Drainage will eventually receive various management activities. The East Fork and Main Fork Watersheds drain 3561 acres and 4169 acres, respectively.

Within the Main Fork Watershed there are ten instrumented sub-watersheds located on the south facing, high energy slopes (Figure 1).

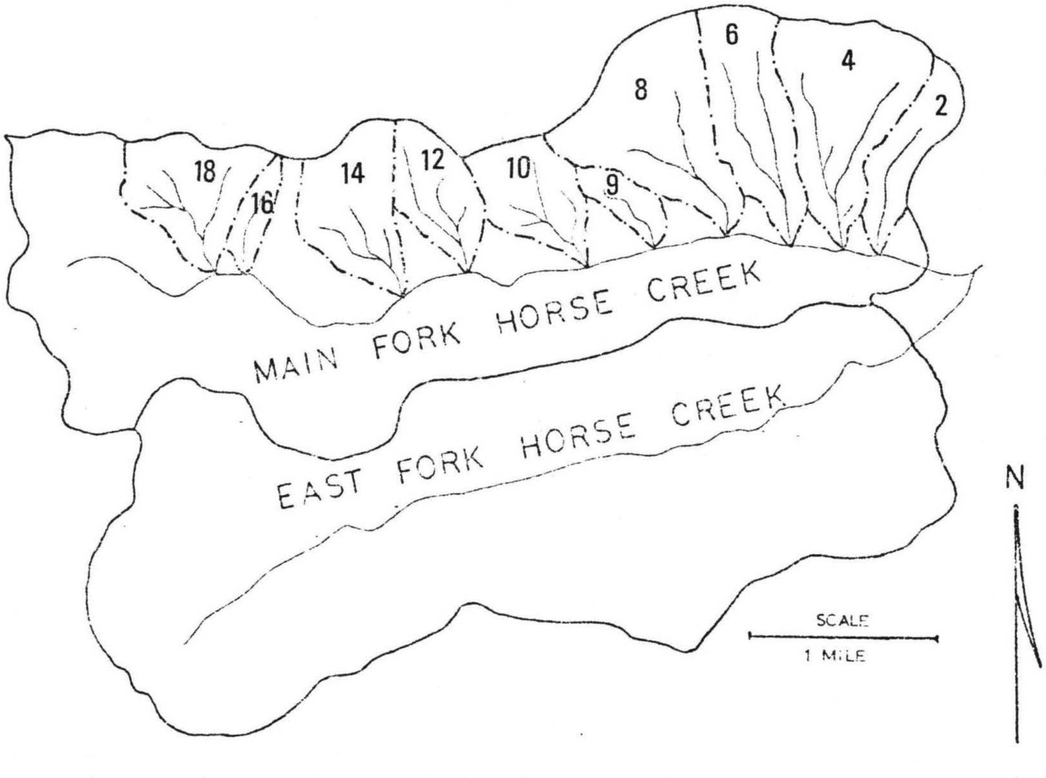


Figure 1. Drainages included in the Horse Creek Administrative Study Area.

These ten subwatersheds, varying in size from 58 to 364 acres, were investigated in this study. A more detailed description of the subwatersheds follows in a subsequent section.

Physiography:

The Horse Creek Watersheds are a part of the Selway Moderately Dissected Lands Subsection (Arnold 1975). This land class is a highly dissected portion of an old erosion surface. However, Hughes (1965) states that the eastern three fourths of the Horse Creek Watershed is more youthful, exhibiting lower drainage densities and steeper stream gradients.

The East Fork and Main Fork of Horse Creek drain eastwardly. Elevations range from 6,000 feet at the southern divide of the East Fork Watershed to 4,100 feet at the confluence. The mean elevations for the Main Fork and East Fork Watersheds are 4,990 and 5,190 feet, respectively. These watersheds have convex side slopes that often exceed 65 percent on the lower slopes. Slopes tend to be more gentle on the upper side slopes and near the head of the watersheds. Median side slopes for the Main Fork and East Fork Watersheds are 31 and 36 percent, respectively.

Geology:

These watersheds are located on the border of the Idaho Batholith, a large igneous intrusion in central Idaho and western Montana. These border zone rocks are part of the Belt Super Group (Bennett 1974) composed of sedimentary and metasedimentary rock of primarily gneissic material (Greenwood and Morrison 1967). This gneissic rock contains large proportions of quartz, plagioclase, biotite, and muscovite (Hughes 1965).

The local stream base is controlled by resistant quartzites located 0.75 miles below the confluence of the East and Main Forks. The streams above this point are not graded and channel downcutting and extension are dominant processes.

Soil:

The deep weathered gneissic regolith is sandy but with a substantial proportion of silts and clays. Alvis (1965) conducted a soil survey of the Horse Creek study area and found the most commonly occurring soil type in the ten subwatersheds was a moderately deep, well drained, sandy loam to loam, tentatively classified as the Jughandle series. The thick surface layers of this soil contain much loessial silt.

The other soil type common to these subwatersheds is a moderately shallow, well drained, loam to sandy loam. These soils are found on the steep slopes in the lower portions of the subwatersheds. The potential for surface erosion on this soil type is high.

Vegetation:

These watersheds are almost completely forested with the exception of creek bottoms along the Main Fork and some meadows along the upper drainage divide. The predominant tree species are grand fir (*Abies grandis*), western redcedar (*Thuja plicata*), western larch (*Larix occidentalis*), Englemann spruce (*Picea englemannii*), and lodgepole pine (*Pinus contorta*). Important browse species are willow (*Salix* sp.), serviceberry (*Amelanchier* sp.), ceanothus (*Ceanothus* sp.), mountain maple (*Acer glabrum*) and pacific yew (*Taxus brevifolia*).

Climate and Hydrology:

The Horse Creek Watersheds are affected by modified marine air masses from the Pacific Ocean. The average annual precipitation is 45 inches with the wettest and driest months being January and August, respectively. Approximately 60 to 70 percent of the precipitation occurs as snowfall.

The average annual temperature is 37 degrees Fahrenheit. The warmest month, August, averages 59 degrees Fahrenheit while January, the coldest month, averages 17 degrees Fahrenheit.

The annual hydrographs are characterized by 2 to 4 weeks of high flows, the result of snowmelt during May and June. Summer low flows are reached by late August. During the late fall and winter months flows are slightly greater than the summer low flows. Annual streamflow amounts to approximately 40 percent of the annual precipitation.

GEOMORPHOLOGICAL CLASSIFICATION

The value of many research efforts in the field of watershed management can be measured in their ability to provide useful information applicable to a large geographical region. In many instances it is difficult to extrapolate information to other watersheds with a high degree of reliability. This is because many variables influence hydrologic relationships and these variables may be different for watersheds in other geographical areas.

Time and cost requirements for most watershed studies prohibit experiment replication for each geologic type, vegetation type, climatic zone, etc. Thus, attempts are made to extrapolate results, often with a low degree of reliability in the estimates.

The results obtained from a given watershed experiment are in part regulated by the physical characteristics of the watershed. If geomorphic variables could be used as an aid in either defining relationships or in extrapolation of information, this would reduce the magnitude of the problem now facing watershed managers.

The ten Horse Creek Subwatersheds are similar in that they occur within the same physiographic province, have similar geologies, soils, vegetation, and climate. Therefore, they exhibit hydrologic properties and water quality characteristics that are in many ways similar. Snyder (1976) has shown that forested watersheds in northern Idaho and western Montana with similar geologies have many similar water quality characteristics. However, even within a given geologic type there is variation in water quality characteristics which may be partially influenced by the geomorphology of the individual watersheds.

This section of the report will define the geomorphological properties of the Horse Creek Subwatersheds and explore their usefulness in explaining differences in the sedimentation characteristics of the watersheds. Twenty-nine variables (Table 1) were used to describe the physical attributes of the subwatersheds. Appendix 1 and 2 respectively define each of these variables and give their values for the ten subwatersheds.

The one variable that requires some explanation is Inherent Watershed Stability developed by personnel on the Clearwater National Forest (Bennett and Wilson 1975). This is an index of the watersheds ability to produce sediment. This subjective index utilizes land type or land type groups weighted by erodibility. A land type is defined as "an area of land with similar soil and vegetative patterns, geology and slope hydrology characteristics." Other researchers support this systematic approach in describing the land system (Wertz and Arnold 1973).

Table 1. The geomorphic characteristics of the Horse Creek Subwatersheds.

Type of Variable	Geomorphic Variable	Symbol	Units
Basin Geometry:	Area of the basin	A	Miles^2
	Basin perimeter	P	Miles
	Maximum length of the basin	L_b	Miles
	Maximum width of the basin	Br	Miles
	Lemniscate ratio	Lr	-
	Lemniscate constant	K	-
	Basin circularity	R_c	-
	Basin width factor	R_w	-
	Basin elongation	R_e	-
	Form factor	R_f	-
	Shape factor	R_s	-
	Aspect	α	Degrees
Measures Involving Heights:	Mean elevation	$\overline{E}$	Feet
	Total basin relief	R	Miles
	Relief ratio	R_h	-
	Ruggedness number	R_n	-
Drainage Network:	Total stream length	L	Miles
	Length of first order streams	L_1	Miles
	Length of second order streams	L_2	Miles
	Mean length of first order streams	$\overline{L}_1$	Miles
	Mean length of second order streams	$\overline{L}_2$	Miles
	Number of first order streams	N_1	Number
	Number of second order streams	N_2	Number
	Total number of streams	N	Number
	Stream length ratio	R_1	-
	Drainage density	D	Miles^{-1}
	Stream frequency	F	No./miles^2
	Texture ratio	T	No./mile
Watershed Stability:	Inherent watershed stability	S	-

This land classification system is based upon landforming processes and their extent of development for land typing. A detailed outline of this procedure is reported in the Clearwater National Forest Watershed Analysis Procedure (Bennett and Wilson 1975).

The Horse Creek Subwatersheds land types were determined by personnel on the Clearwater National Forest. Table 2 is a list of those land types that occurred. Appendix 3 gives the area of each subwatershed that was classified in the different land types.

Table 2. Land types occurring in the Horse Creek Subwatersheds.

Landforming Process	Degree of Expression	Secondary Process Modifiers	Land Type
Fluvial	late-mature	moderate frost churning	21F
	mid-mature		22
	mid-mature	moderate frost churning	22F
	early-mature		24
	early-mature	moderate frost churning	24F
	early-mature	weak frost churning	24C
Colluvial Drift and Frost Churned Slopes	colluvial drift		30
	colluvial drift	weak subsurface frost churning (weak cryoplanation)	31
	colluvial drift	moderate subsurface frost churning (moderate cryoplanation)	32
Mass Wasted	moderately dissected	solifluction	51H
Breaks	stream breaks, mid-stage	weak fluvial action	61C

Each land type is assigned an on-site land type hazard based on the underlying geologic formations. The off-site land type hazard is then calculated for the land type by multiplying the on-site hazard by a delivery ratio (0 to 1). This delivery ratio is defined as the relationship of rate of reaction of the land to a given treatment. Thus, it is a relative ranking of how efficient the drainage is in transporting sediment out of the basin. The off-site hazards are then weighted by area of their respective land types and summed for all types in the subwatershed to get an index of the inherent watershed stability.

Principal Component Analysis: Methods and Analysis

The basic concept in PCA is that it attempts to explain relationships between numerous variables in terms of simple relations. It does this by generating a smaller number of hypothetical variables called components (Cattell 1965). The properties of the new components are: 1) they are linear functions of the original variables; 2) the total variation among them is equal to the total variation in the original set of variables; 3) the variance associated with each component decreases in order; and 4) the components are orthogonal, independent of each other (Isebrands and Crow 1975). This last property, orthogonality, is most desirable. In most instances, the original set may include numerous variables that are not independent; thus, covariance between the variables must be considered in most statistical procedures. However, in PCA, the transformed variables, components, are independent.

Typically, PCA is used to explore and detect a patterning of variables which may enable the researchers to discover new concepts and/or may lead to a reduction of data. The reduction of the number of variables is carried out through the deletion of extraneous variables, those that do not provide much information in distinguishing between individuals.

Additional uses of PCA are as follows: 1) it can be used to generate indices that may be used as new variables in subsequent analysis (Rice 1970); 2) PCA can be used to test hypothesis about the structure of variables (Nie, et al. 1975); 3) it can be used in conjunction with regression analysis and other statistical techniques (Cox 1968, Wallis 1968, Jeffers 1967) and 4) it can be used to identify important variables (Wallis and Anderson 1965, Anderson 1966).

The set of previously described geomorphic characteristics describes the physical attributes of these watersheds. However, a small sample (ten subwatersheds) and a large number of variables (29 geomorphic descriptors), many of which are highly correlated creates an analytical problem. It would be desirable to identify those variables which explain the important differences between subwatersheds and to avoid statistical problems that arise from lack of independence. One method of achieving these goals is through the use of principal component analysis.

The initial step in this procedure is the construction of a correlation matrix for the variable set. An evaluation of the pairwise relationships can be used as an aid in discarding variables. If two or more variables are very highly correlated, then they supply similar information and one or more should be discarded. This discarding procedure is neither a prerequisite nor a hindrance to PCA, but rather a method to reduce the size of the variable set. On this basis, nine variables were deleted from further consideration (Table 3). Appendix 4 gives the correlation matrix for the remaining 20 variables.

Table 3. Geomorphic variables discarded from PCA due to high correlations with another variable.

Discarded Variables
lemniscate ratio
basin elongation
basin width factor
shape factor
form factor
mean length of second order streams
total stream length
total number of streams
area of the basin

Principal component analysis was performed on the correlation matrix for the remaining variables. It extracts one component for every variable. The first component will account for the largest percentage of the variation in the original matrix. Each subsequent component will account for less variance (Table 4). Only the first nine components are shown since they explain 100 percent of the variance in the original correlation matrix.

Kaiser's rule (Jeffers 1964) states that components with corresponding eigenvalues greater than unity may be extracted for small sized samples. The first five components (Table 4) meet this criteria and may be legitimately extracted. These five components explain 96.1 percent of the variance in the correlation matrix of twenty variables. Thus, with a very small loss of information the data set is simplified into five components.

Table 4. The results of principal component extraction from the correlation matrix of twenty geomorphic variables.

Component	Eigenvalue	Percent of Variance Explained	Cummulation Percent of Variance Explained
1	8.17	40.9	40.9
2	5.16	25.8	66.7
3	3.11	15.6	82.2
4	1.61	8.1	90.3
5	1.16	5.8	96.1
6	0.46	2.3	98.4
7	0.17	0.9	99.3
8	0.10	0.5	99.7
9	0.05	0.3	100.0

A component pattern matrix may be generated for these five components. This matrix expresses the degree of correlation between each variable and each component. However, the component structure may be simplified by rotation of the components in five dimensional space. There are numerous types of rotations which may be employed in PCA. In this analysis orthogonal varimax rotation (Kaiser 1958) was used to simplify the columns of the component pattern matrix (Table 5). This is the most widely used type of orthogonal rotation. Kaiser (1958) reports that one important advantage of this type of rotation is that it is stable under changes in the composition of the data set.

The corresponding eigenvalues and the percent of the total variance explained by each component changes slightly (Table 6). However, the same amount of the total variance in the original data set is explained.

Table 5. The varimax rotated component matrix for the twenty geomorphic variables describing the Horse Creek Subwatersheds.

Geomorphic Variable	Component 1	2	3	4	5
L_b	-0.06	0.97	0.17	0.06	-0.12
Br	0.64	0.60	-0.30	-0.33	0.04
P	0.21	0.91	-0.31	-0.20	0.02
K	-0.92[1/]	-0.13	0.16	0.29	-0.03
R_c	0.88	-0.09	0.22	0.10	-0.38
R_h	-0.21	-0.21	0.92	0.07	0.15
R_n	0.07	0.38	0.23	0.88	-0.14
R	-0.14	0.92	0.35	0.09	-0.02
T	0.94	-0.09	0.01	0.31	-0.08
F	0.74	0.52	0.05	0.37	-0.10
D	0.18	0.57	-0.10	0.77	-0.16
R_1	0.89	0.06	-0.28	0.04	0.19
N_1	0.93	0.21	-0.08	0.24	0.07
N_2	0.79	0.45	0.28	0.09	-0.19
$\bar{L}_1$	-0.83	0.48	-0.01	0.17	-0.04
L_1	0.35	0.78	-0.22	0.40	-0.05
L_2	0.77	0.42	-0.45	0.03	0.05
$\bar{E}$	0.37	-0.29	0.01	-0.16	0.72
α	-0.34	0.21	0.32	0.02	0.85
S	0.07	0.13	0.54	0.41	-0.65

[1/] Geomorphic variables with absolute values greater than 0.80 for a given component are a) the most important variables defining the component and 2) theoretically should be useful in explaining differences between subwatersheds.

Table 6. The corresponding eigenvalues and variance explained by each of the five components following varimax rotation.

Component	Eigenvalue	Percent of Variance Explained	Cumulative Percent of Variance Explained
1	7.56	37.8	37.8
2	5.19	26.0	63.8
4	2.32	11.6	75.4
3	2.14	10.7	86.1
5	2.00	10.0	96.1

Principal Component Analysis: Results

Varimax rotation simplifies the structure of the component pattern matrix, making it easier to interpret. Those variables with high numerical values in the first component (absolute value > 0.80) are lemniscate constant, basin circularity, texture ratio, stream length ratio, number of first order streams, and the mean length of first order streams (Table 5). These geomorphic characteristics describe the shape-dissection properties that are important in distinguishing between subwatersheds. The maximum length, perimeter length, and relief have high values on the second component. These variables index the area-slope of the subwatersheds. The remaining three components have a single variable with a high value; relief ratio, ruggedness number, and aspect for components three through five, respectively. Those variables that had small variables on all components are maximum width, stream frequency, drainage density, length of first order streams, length of second order streams, mean elevation and on-site sediment production hazard. These variables do not aid in distinguishing between subwatersheds in this analysis and are candidates for possible deletion.

Component scores can be calculated and used as an index of geomorphic differences between subwatersheds (Table 7). These scores are calculated using the values in the varimax rotated component matrix (Table 5) and the standardized value of each variable for each subwatershed. The relationship between the rotated component pattern matrix and component scores is discussed in Gorsuch (1974). These component scores can be used to distinguish between the subwatersheds.

Table 7. Component scores for the ten Horse Creek Subwatersheds based on principle component analysis of twenty geomorphic variables.

	Components				
Subwatershed	1	2	3	4	5
2	-1.3158	0.6741	1.6884	-0.0130	0.4778
4	0.5012	1.4890	-0.2872	0.2943	0.4569
6	-0.9438	1.0915	-1.4743	1.5090	0.2825
8	0.0477	0.8885	-0.7606	-2.3006	-7.7341
9	-1.0934	-1.5541	-0.5831	-0.0895	-1.2560
10	1.1244	-0.5514	0.1719	1.0984	-0.6364
12	0.5351	0.0015	0.4711	0.0271	-0.7784
14	0.9453	-0.4454	1.1982	-0.0286	-0.4558
16	-1.0105	-1.0797	0.1285	-0.2929	1.5871
18	1.2097	-0.5139	-1.1271	-0.2042	1.6215

Components one and two, the two most important components with respect to the amount of variance they explain, were used to group the Horse Creek Subwatersheds (Figure 2). Groupings were based on the individual subwatershed component scores for the first two components, the shape-dissection and area-slope components. These are the two most important components with respect to the amount of variance they explained in the data set. Group I is comprised of subwatersheds 10, 12, 14, and 18; group II, subwatersheds 4, 6, and 8; and group III, subwatersheds 2, 9, and 16. Subwatershed 2 was grouped with 9 and 16 based on the similarity of scores for the first component.

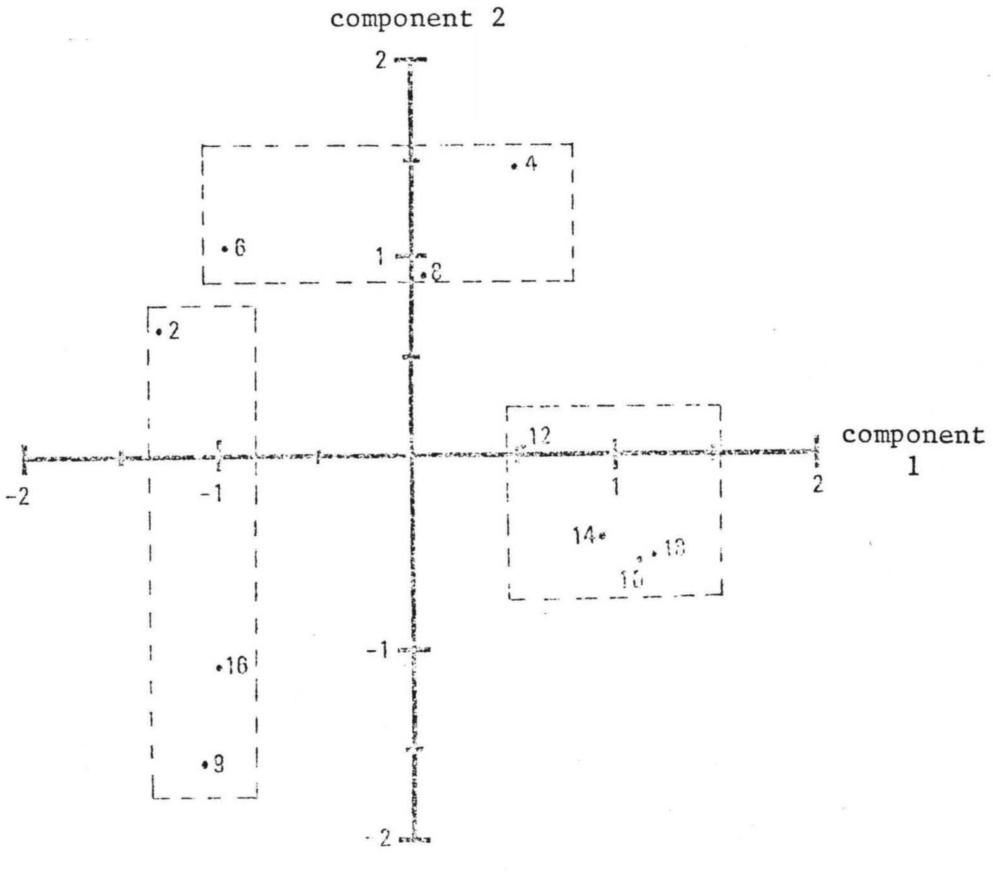


Figure 2. Groupings of the Horse Creek Subwatersheds based on scores of the first two components extracted in principal component analysis.

Based upon the PCA, several hypotheses can be stated. 1) Subwatersheds which can be grouped together based on the component scores exhibit similar sedimentation relationships. This would be the case if geomorphology has a significant influence on sedimentation processes. 2) Variables which had high values in the rotated component matrix, especially those variables with high values for the first two components, are important characteristics governing sedimentation processes. 3) Variables with high values are useful as predictor variables when used in regression analysis. Cox (1968) advocated the use of PCA to suggest regressor variables. His criteria was to select those variables that had the highest value for each component in the rotated component matrix. If more than one variable had a high value, then all variables with high values ($> |0.08|$) will be candidates for regressor variables. Based on these criteria, maximum width, perimeter length, lemniscate constant, basin circularity, relief ratio, ruggedness number, relief, texture ratio, stream length ratio, number of first order streams, mean length of first order streams and aspect should be important variables in distinguishing between the sedimentation processes on the ten subwatersheds, if in fact, sedimentation is governed by geomorphology.

BEDLOAD SEDIMENT

Bedload sediment consists of particles transported in the channel by rolling or sliding on the bed or by bouncing into the flow and then resting (saltation). Bedload transport rates are governed by the availability of upstream sediment of particular size classes and the transport capability of the stream. For a given discharge the size of the material transported as bedload is determined by shape, density, and the turbulent intensity of the flow. In many watersheds bedload is only a small percentage of the total load, but it is important in shaping the bed, influencing channel stability, functional hydraulic resistance and the energy grade line (Shen and Li 1976).

Bedload yields vary from year to year as a function of climate and sediment supply. The magnitude of peak flow and the duration of high flows regulate the potential for yields of bedload material. Variability is also caused by changes in the upstream sediment supply. For example, Megahan (1976b) measured stored sediment in selected channels draining small forested watersheds in central Idaho and found that storage varied considerably between years. However, only 10 percent of the stored sediment appeared in the annual sediment yield. Thus, large volumes of stored sediment remained in the channel available for transport during periods of exceptionally high stream flow.

In the Horse Creek Subwatersheds there is little evidence of surface erosion. It is believed that the predominant processes contributing sediment are channel cutting and extension and creep of the valley side slopes to the channels. Rosgen (1975), Anderson (1975) and Megahan (1976a) have shown that sediment derived from channel erosion contributes a significant portion of the annual sediment yield especially for forested watersheds.

Methods:

Bedload rates were measured using a Helley-Smith portable sampler designed for use on streams with gravel beds (Helley and Smith 1971). The bedload material entering the three inch by three inch orifice was caught in a 200 micron mesh nylon bag. Therefore, bedload sediment is defined as particles greater than 200 microns in diameter. Particles may block the openings in the mesh resulting in the capture of smaller diameter particles. The magnitude of this process was not determined, but is believed to be small.

Bedload transport rates were measured at permanent sampling sites at the mouths of the ten subwatersheds. Bedload transport rates were measured at several points in the channel cross section, the number being a function of stream width. The duration of the sampling varied from ten to sixty minutes with the longer durations being used during lower flows. Channel width, depths and stream discharge were measured at each location.

Sampling commenced near the peak of the snowmelt season during both water years (Oct. 2 to Sept. 30). Inaccessibility to the watersheds prevented sampling at earlier dates. Sampling frequency varied due to accessibility problems; however, in general the sampling was more frequent during high flows and less frequent as bedload rates diminished with decreasing discharge. Sampling was discontinued in late June or July.

The particle size distribution was determined for each sample using sieves with mesh diameters of 12.25 mm, 2.00 mm, 1.00 mm, 0.50 mm, 0.25 mm, and 0.10 mm. The dry weight and ashed (inorganic) weight were determined for each particle size fraction. Bedload transport rates in grams/hour were calculated for each sample using the ashed weights. Samples that were less than 0.10 grams were not sieved.

Analysis and Results:

The percentage of the total ashed sediment, on a weight basis, represented by each sieved fraction was determined and a semilogarithmic cumulative curve was created by plotting the cumulative percentage of successive larger fractions against the mean diameter for each fraction. D_{10}, D_{50}, D_{60}, and D_{90} diameters were read off the curves and used in sample comparison. The heterogeneity of the sample was estimated using the D_{60}/D_{10} ratio (Schwoerbel 1970). The effective mean diameter, D_e, for each sample was calculated by summing the products of ashed weight and median diameter for each fraction and dividing by the total ashed weight for the sample.

The distribution of particle sizes of transported bedload material is not only a function of discharge but also the upstream supply of sediment. Thus, there is considerable variability in the particle size distribution curves shown in Figures 3a-3e. Only particle size distribution curves for 1975 are shown, but they illustrate a general trend of increased particle size as stream discharge increases. The particle size distribution curves for 1976 samples are shown in Appendix 5. Table 8 shows the D_e and stream discharges for the sampling dates in 1975 and 1976. A correlation analysis was made between the common logarithms of stream discharge and the descriptors of the particle size distribution curves (Table 9). Although not all of these correlations were not statistically significant, there were demonstrable direct relationships between the particle size of transported bedload sediment and the stream discharge. There were not consistent relationships between the heterogeneity of the sample and stream discharge.

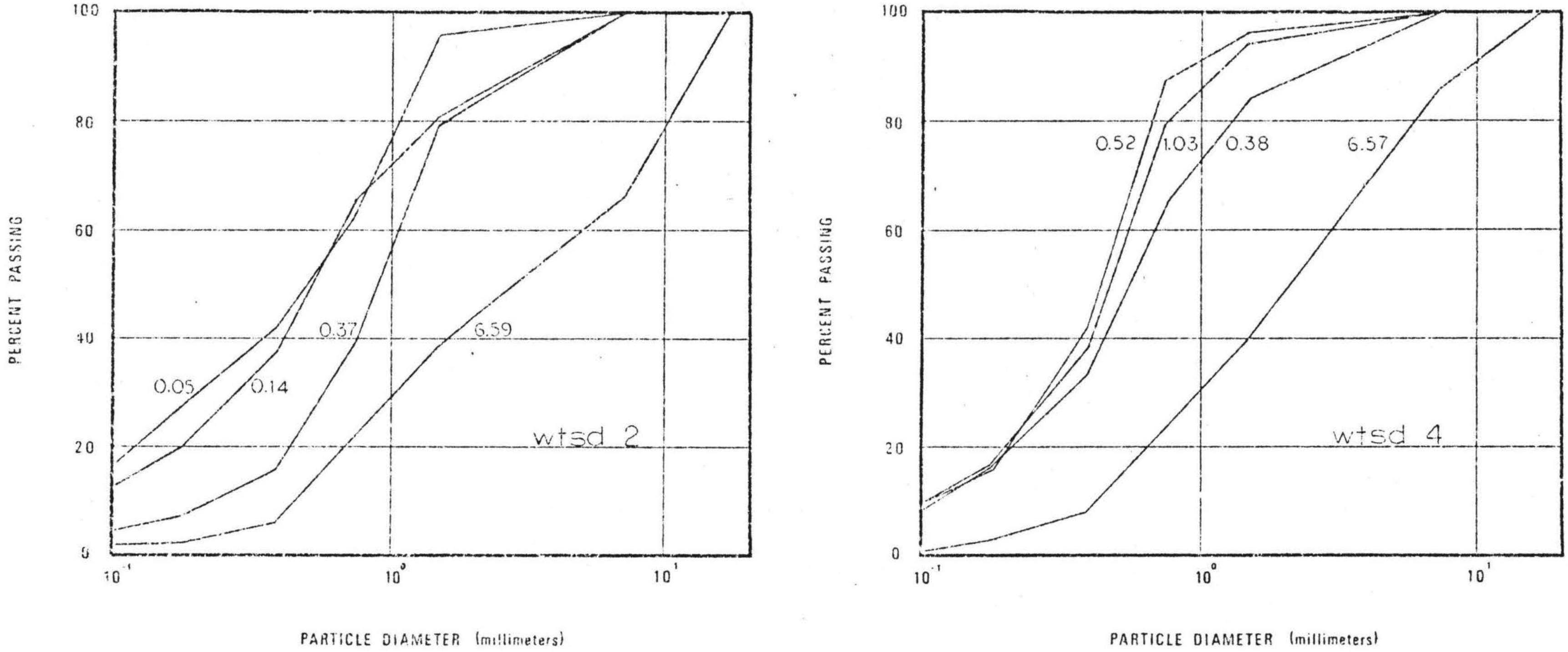


Figure 3a. Particle size distribution of bedload samples collected during water year 1975 on the Horse Creek Subwatersheds 2 and 4.

Note: The number adjacent to each curve denotes the stream discharge in cubic feet per second at the time of sampling.

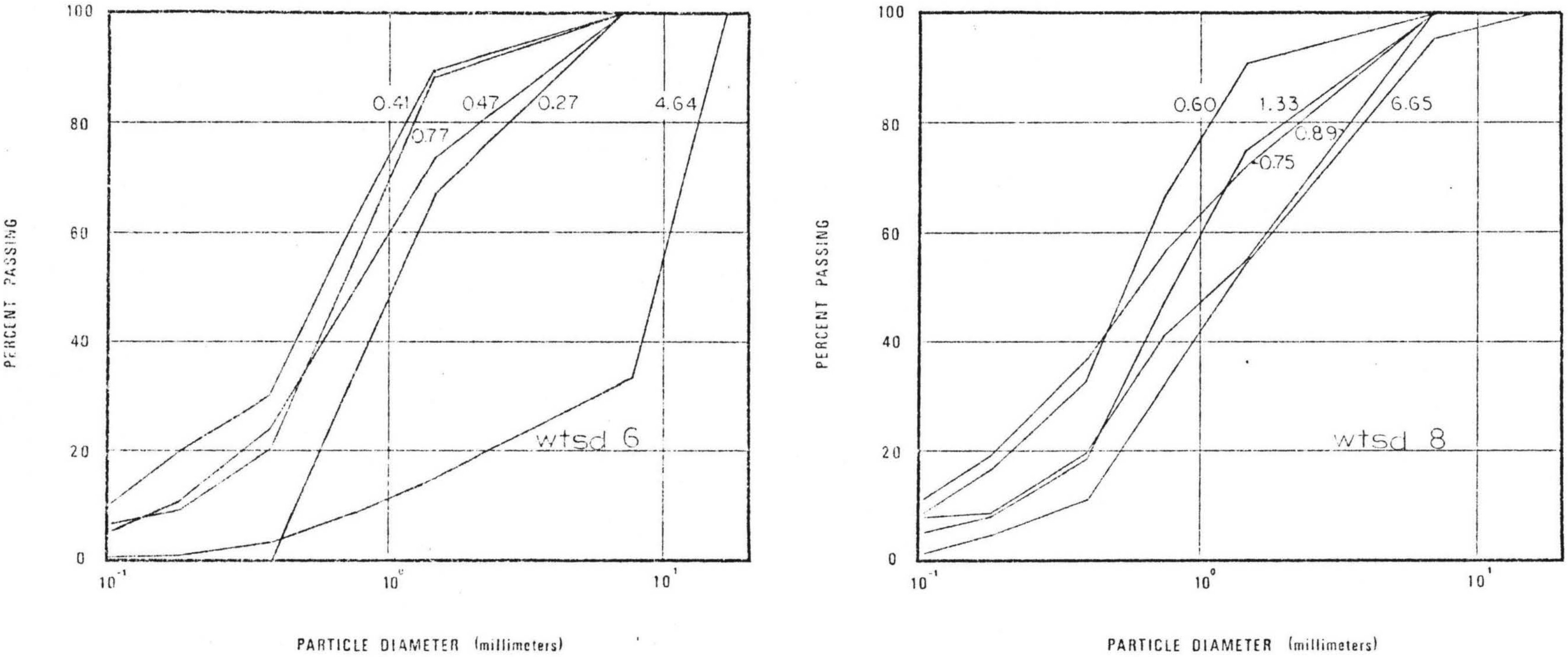


Figure 3b. Particle size distribution of bedload samples collected during water year 1975 on the Horse Creek Subwatersheds 6 and 8.

Note: The number adjacent to each curve denotes the stream discharge in cubic feet per second at the time of sampling.

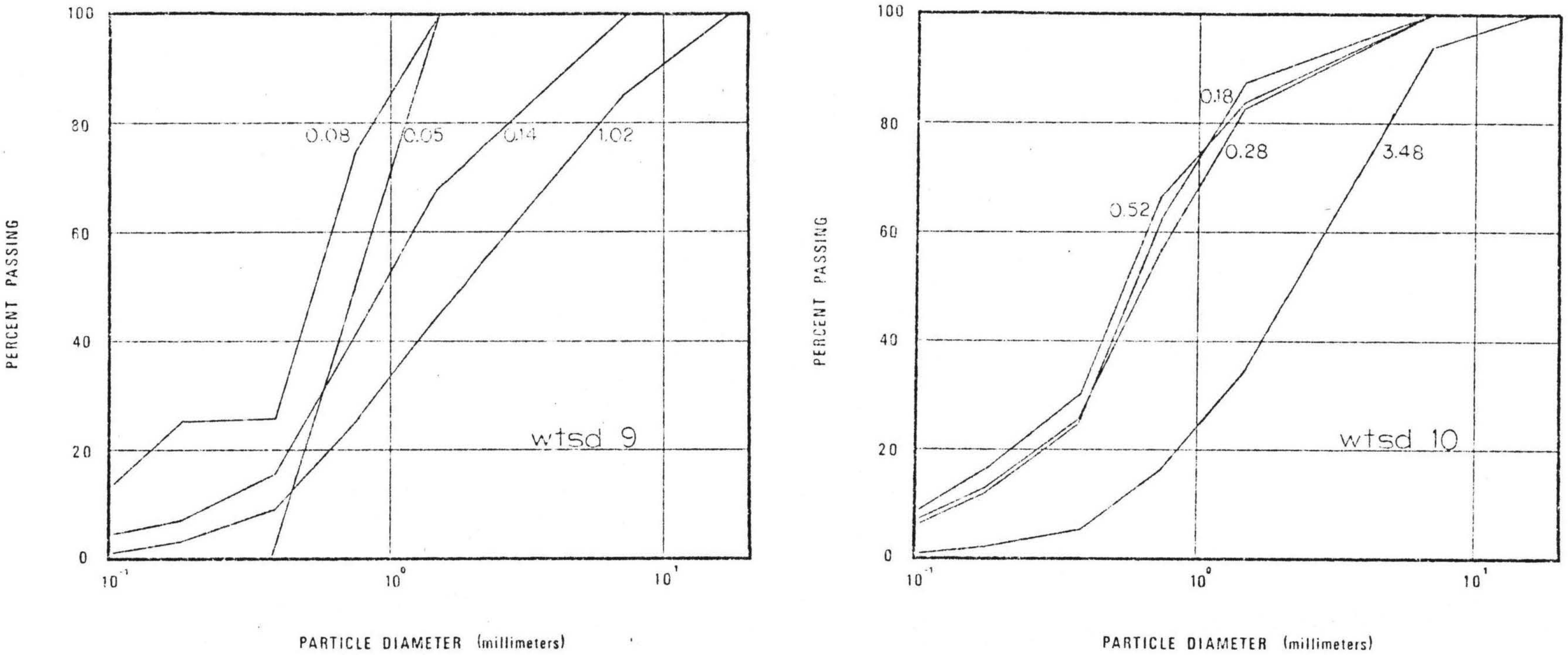


Figure 3c. Particle size distribution of bedload samples collected during water year 1975 on the Horse Creek Subwatersheds 9 and 10.

Note: The number adjacent to each curve denotes the stream discharge in cubic feet per second at the time of sampling.

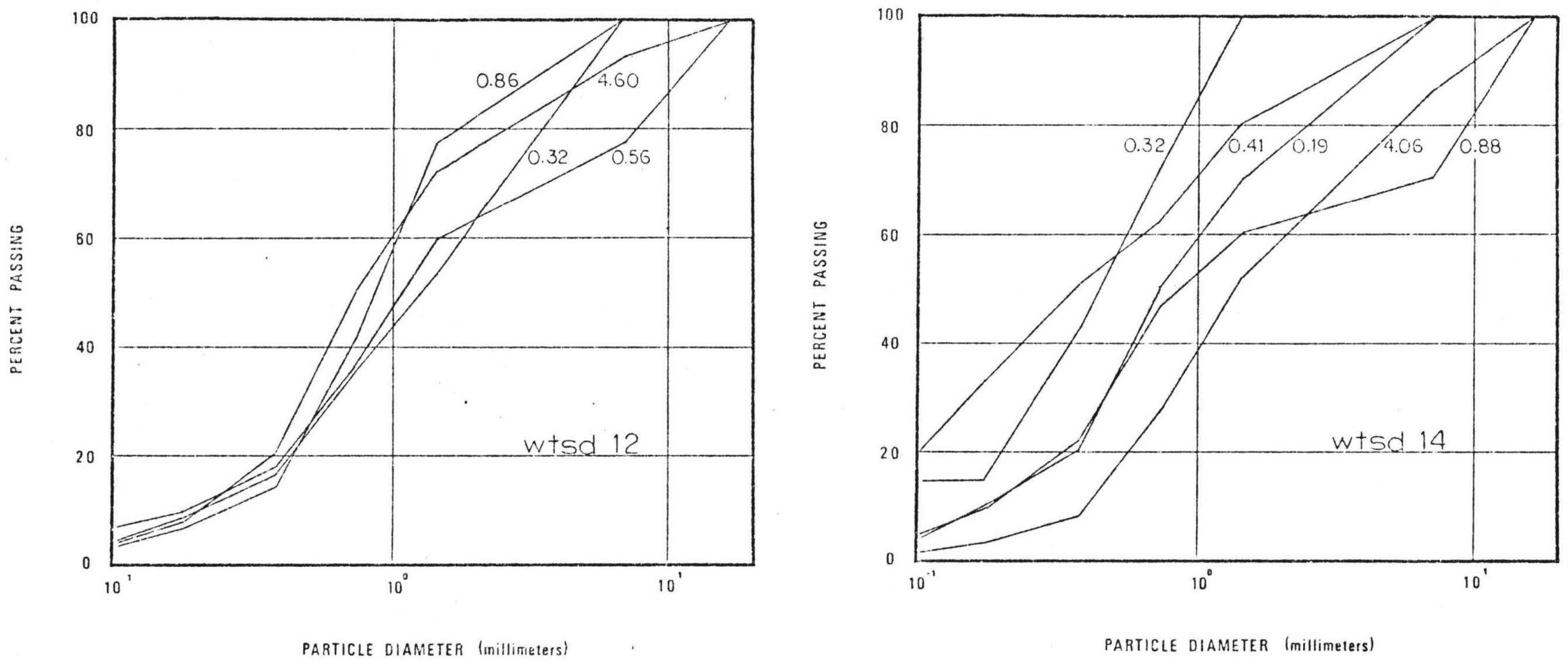


Figure 3d. Particle size distribution of bedload samples collected during water year 1975 on the Horse Creek Subwatersheds 12 and 14.

Note: The number adjacent to each curve denotes the stream discharge in cubic feet per second at the time of sampling.

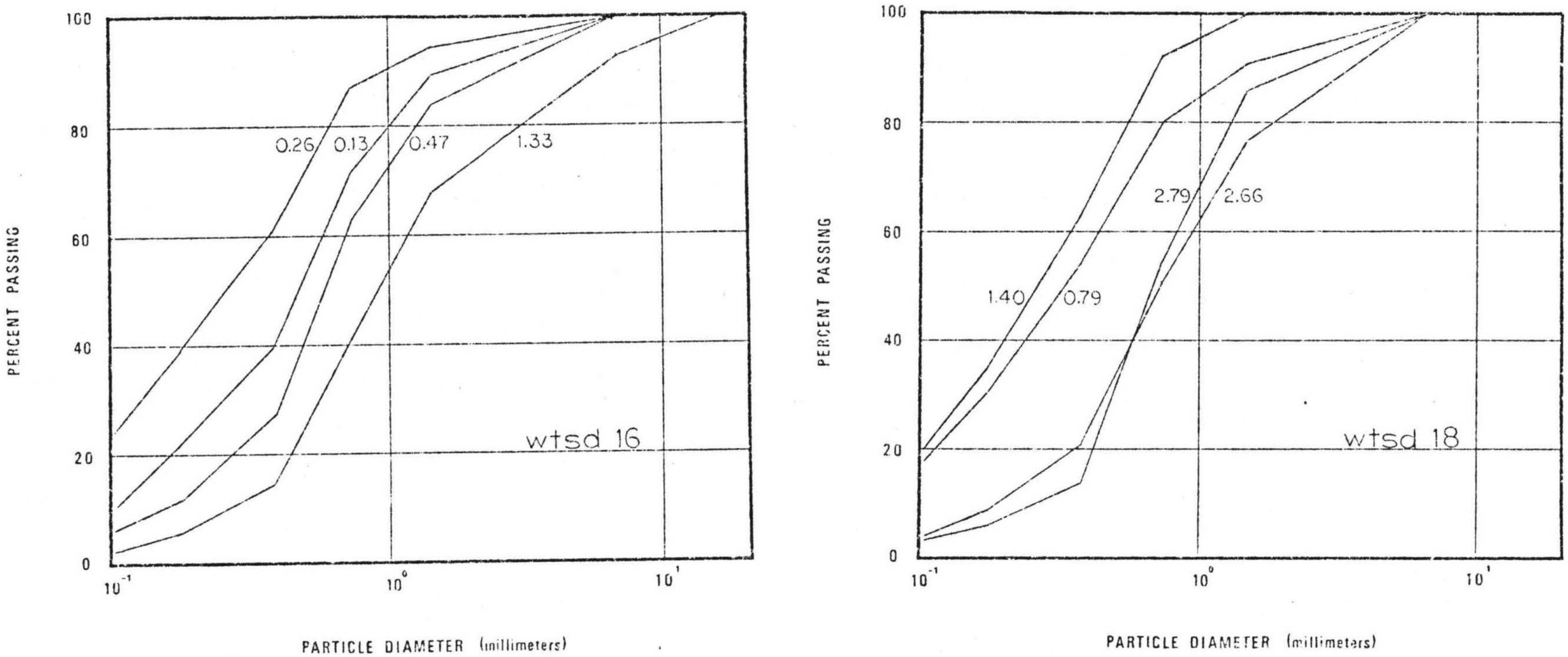


Figure 3e. Particle size distribution of bedload samples collected during water year 1975 on the Horse Creek Subwatersheds 16 and 18.

Note: The number adjacent to each curve denotes the stream discharge in cubic feet per second at the time of sampling.

Table 8. Stream discharges (cubic feet per second) and effective bedload diameters (millimeter) for given sampling dates on the ten Horse Creek Subwatersheds. The bottom value in each pair of values is stream discharge.

Rates	Subwatersheds									
	2	4	6	8	9	10	12	14	16	18
June 4-5, 1975	8.55	6.49	13.76	4.34	6.04	5.82	3.34	5.48	3.77	2.42
	1.80	6.57	4.46	6.65	1.02	3.48	4.60	4.06	1.33	2.66
June 28-30, 1975	2.33	1.01	1.67	2.48	2.96	1.80	2.43	6.58	1.84	1.86
	0.37	1.03	0.77	1.33	0.14	0.52	0.86	0.88	0.47	2.79
July 9-10, 1975	1.98	0.86	2.58	3.71	0.79	2.01	5.87	1.92	0.83	0.50
	0.14	0.52	0.47	0.89	0.08	0.28	0.56	0.41	0.26	1.40
July 16-17, 1975		1.82	1.48	2.50				0.76		
		0.38	0.41	0.75				0.32		
July 31-	1.02		3.20	1.33	1.13	1.64	3.84	2.79	1.40	1.23
August 1, 1975	0.05		0.27	0.61	0.05	0.18	0.32	0.19	0.13	0.79
Mar. 10-11, 1976	7.28	2.92	2.78	4.47	2.61	6.10	2.32	5.17	2.16	2.08
	2.59	10.17	6.84	9.16	1.53	4.79	6.02	4.81	1.80	1.76
May 12-14, 1976	5.80	1.57		5.40	2.14	2.96	7.51	3.76	1.46	2.58
	2.01	7.86		7.30	1.10	4.15	5.65	4.54	1.78	2.69
May 17-19, 1976	1.66	1.23	1.43	7.39	1.28	1.12	9.72	1.72	1.38	6.88
	1.23	4.25	3.26	6.34	0.75	2.20	3.93	3.27	1.44	3.54
May 20-21, 1976	1.92	0.72	1.07	1.48	0.65	2.22	4.46	1.52	4.52	6.20
	1.04	3.48	2.69	4.77	0.53	1.71	3.27	2.68	1.30	3.70
June 2-6, 1976	2.22	0.84		1.11	1.00		0.71	3.08	0.80	4.30
	0.47	1.41		2.04	0.21		1.18	0.90	0.56	3.02

Table 9. Correlation coefficients for the pairwise relationship between the common logarithms of stream discharge (cfs) and bedload diameters (mm) for the Horse Creek Subwatersheds (significance levels are indicated by +, α = .10; *, α = .05; and **, α = .01).

	Subwatersheds									
	2	4	6	8	9	10	12	14	16	18
1975										
D_e	0.98*	0.82	0.81+	0.70	0.90+	0.95*	-0.32	0.63	0.80	0.55
D_{90}	0.97*	0.77	0.71	0.60	0.91+	0.96*	-0.14	0.62	0.84	0.61
D_{60}	0.87	0.94+	0.93*	0.69	0.96*	0.93+	-0.84	0.87*	0.84	0.85
D_{50}	0.95*	0.92+	0.89*	0.75	0.81	0.92+	-0.95*	0.73	0.71	0.83
D_{10}	0.96*	0.94+	0.96**	0.94*	0.97*	0.92+	0.26	0.83+	0.89+	0.88
D_{60}/D_{10}	0.06	0.35	-0.32	-0.28	0.91+	-0.49	-0.19	0.12	0.91+	-0.48
1976										
D_e	0.74	0.83+	0.99+	0.82+	0.74	0.76	0.72	0.22	0.52	0.92*
D_{90}	0.71	0.82+	0.99+	0.81+	0.77	0.69	0.76	0.23	0.44	0.90*
D_{60}	0.68	0.97**	0.99**	0.47	0.88*	0.72	0.34	0.30	0.24	0.88*
D_{50}	0.54	0.96**	0.99*	0.61	0.98**	0.76	0.55	0.14	0.32	0.93*
D_{10}	-0.15	0.88*	0.99+	0.70	0.87*	0.83	0.31	-0.04	0.50	0.88*
D_{60}/D_{10}	0.77	0.43	0.58	0.59	0.41	-0.17	0.57	0.46	0.29	-0.30

The median diameter, D_{50}, for bedload particles for these subwatershed generally ranges from 0.4 mm during lower flows to greater than 2.0 nn during peak flows. Sand size particles, 0.05 to 2.00 mm, constitute the majority of the material transported as bedload. Silt and clay particles, < 0.05 mm, constituted only a small percentage of the transported material.

A considerable portion of the particulate matter transported in streams is organic. Organic particulates are important to the stream ecology by providing a source of nutrients through decomposition. The percentage of organic material measured as bedload was highly variable for these subwatersheds (Table 10). For individual samples of bedload, organic matter ranged form 0.8 to 64.4 percent in 1975 and 2.1 to 59.9 percent in 1976. Typically, the percentage of organics increased as stream discharge diminished on the recession limb of the snowmelt hydrograph. This may be due to differential reduction in the stream's capability to transport inorganic particulates than less dense organic particles. The snowmelt in 1976 resulted in higher peak flows than in 1975. During 1976 the percentage of organics was consistently higher for similar stream discharges. This may reflect a flushing of trapped organic matter during high discharges.

There are numerous methods that can be used to model or describe sediment transport processes or sediment yields. There are both deterministic and probabilistic equations available for transport estimation. Additionally, some models not only deal with channel processes, but also with the land phases of erosion and the contribution of eroded material to the channel.

The criterial for model selection must consider the expected use of

Table 10. The mean and range of percent organics for bedload samples collected on the ten Horse Creek Subwatersheds for water-years 1975 and 1976.

Date	Mean Percent Organics	Range Percent Organics
June 5, 1975	3.63	0.84 - 8.74
June 29, 1975	8.41	2.10 - 20.64
July 10, 1975[1/]	31.05	7.474 - 64.36
July 16, 1975[1/]	---	---
July 31, 1975[1/]	---	---
Combined Samples 1975	13.79	0.84 - 64.36
May 11, 1976	14.57	2.09 - 36.69
May 13, 1976	12.63	3.33 - 29.78
May 19, 1976	14.96	3.28 - 31.00
May 21, 1976	17.03	3.55 - 35.14
June 2, 1976[1/]	28.75	3.721 - 59.89
Combined Samples 1976	17.12	2.09 - 59.89

[1/] The percent organics was not determined on one or more samples due to to the small volume of material collected.

the model, the type of potential user, and the time and manpower resources available for quantification of the required inputs. For this study, the uses of the model are to describe the sediment transport processes and to statistically evaluate changes in transport following management activities. Manpower and time resources were limited, which necessitated the use of a simple model requiring a minimum of inputs.

Bagnold (1966) and Rosgen (1975) have demonstrated a relationship between bedload transport and stream power. However, for a particular channel cross-section, stream power is directly related to discharge.

The relationship between bedload transport rates and stream discharge as shown by past research (Johnson and Smith 1977) is parabolic. This relationship can be expressed as:

$$Y = b\,Q^{n} \qquad (1)$$

where, Y = bedload sediment transport rate (gms/hour)

Q = stream discharge (cfs)

n = exponent

b = constant

Equation (1) can be expressed as a linear regression model by logarithmic transformation resulting in:

$$\log Y = \log b + n \log Q + \varepsilon \qquad (2)$$

where, $\log b = \beta_o$ = constant (intercept)

n = constant (slope) = β_1

ε = error

This model (2) was used to relate stream discharge and ashed (inorganic) bedload rates for each subwatershed for 1975 and 1976. Statistical information for these regressions (bedload rating curves) is given in Table 11. The only regression that was not significant ($\alpha = 0.10$) was for subwatershed 18 during 1975. An analysis of covariance was performed on the two regressions on each subwatershed to determine if the relationship had changed between years. The pair of regressions developed for subwatershed 6 was the only case where the 1975 and 1976 regressions were not statistically similar. However, for purposes of uniformity and to include annual variations, the data for the two years were pooled for all subwatersheds. The regressions for the pooled data (Table 11) were highly significant ($\alpha = 0.01$).

Table 11. Regression coefficients and statistical information for the bedload rating curves for the Horse Creek Subwatersheds (significance levels are +, $\alpha = 0.1$; *, $\alpha = 0.05$; **, $\alpha = 0.01$).

Subwatershed	Year	$\hat{\beta}_o$	$\hat{\beta}_1$	Standard Error	R^2	Significance
2	1975	3.474	2.072	0.264	0.98	*
	1976	3.130	2.048	0.062	0.99	**
	Combined	3.241	1.877	0.211	0.97	**
4	1975	1.948	3.447	0.818	0.88	*
	1976	1.555	2.016	0.452	0.75	+
	Combined	1.563	2.452	0.775	0.79	**
6	1975	2.349	3.930	0.649	0.92	*
	1976	0.731	4.158	0.248	0.97	*
	Combined	1.804	2.930	0.797	0.80	**
8	1975	1.599	3.459	0.500	0.92	*
	1976	0.752	3.837	0.245	0.95	**
	Combined	1.485	3.045	0.435	0.92	**
9	1975	4.476	3.481	0.882	0.89	+
	1976	2.551	2.532	0.197	0.95	**
	Combined	2.919	2.209	0.868	0.68	**
10	1975	2.699	3.158	0.231	0.99	**
	1976	1.827	3.370	0.642	0.84	*
	Combined	2.278	2.759	0.591	0.88	**
12	1975	2.757	2.324	0.451	0.91	*
	1976	1.606	3.409	0.326	0.92	**
	Combined	2.503	2.119	0.498	0.82	**

Table 11 (continued).

Subwatershed	Year	$\hat{\beta}_o$	$\hat{\beta}_1$	Standard Error	R^2	Significance
14	1975	2.336	3.036	0.539	0.92	*
	1976	2.127	2.448	0.541	0.70	+
	Combined	2.146	2.643	0.505	0.90	**
16	1975	3.840	3.712	0.139	0.99	**
	1976	2.880	3.318	0.565	0.66	+
	Combined	3.166	2.779	0.548	0.83	**
18	1975	2.297	2.271	0.503	0.67	N.S.
	1976	2.614	2.501	0.194	0.79	*
	Combined	2.321	2.866	0.355	0.78	**

Principal component analysis of the geomorphological variables indicated that the subwatersheds could be grouped, based on component scores, into the following groups:

Group	Subwatersheds
I	10, 12, 14, 18
II	4, 6, 8
III	2, 9, 16

If geomorphology influences bedload transport rates, then the rating curves for the subwatersheds should be similar (Figure 4). Within each respective group the rating curves are similar. For each group of subwatersheds the data were combined using equation (2) to generate a single bedload rating curve for each group. These rating curves and statistical information are presented in Figure 5 and Table 12. Appendix 6 shows the individual subwatershed bedload rating curves in relation to the rating curves for their respective geomorphological group. Analysis of covariance indicated that the three group rating curves were statistically different.

Table 12. Regression coefficients and statistical information for the bedload rating curves for the geomorphic groupings of Horse Creek Subwatersheds.

Group	Subwatershed	$\hat{\beta}_o$	$\hat{\beta}_1$	Standard Error	R^2	Significance
I	10,12,14,18	2.2995	2.6065	0.498	0.86	**[1/]
II	4, 6, 8	1.6433	2.7107	0.661	0.82	**
III	2, 9, 16	3.1159	2.2404	0.604	0.79	**

[1/] **Indicates significance at $\propto = 0.01$.

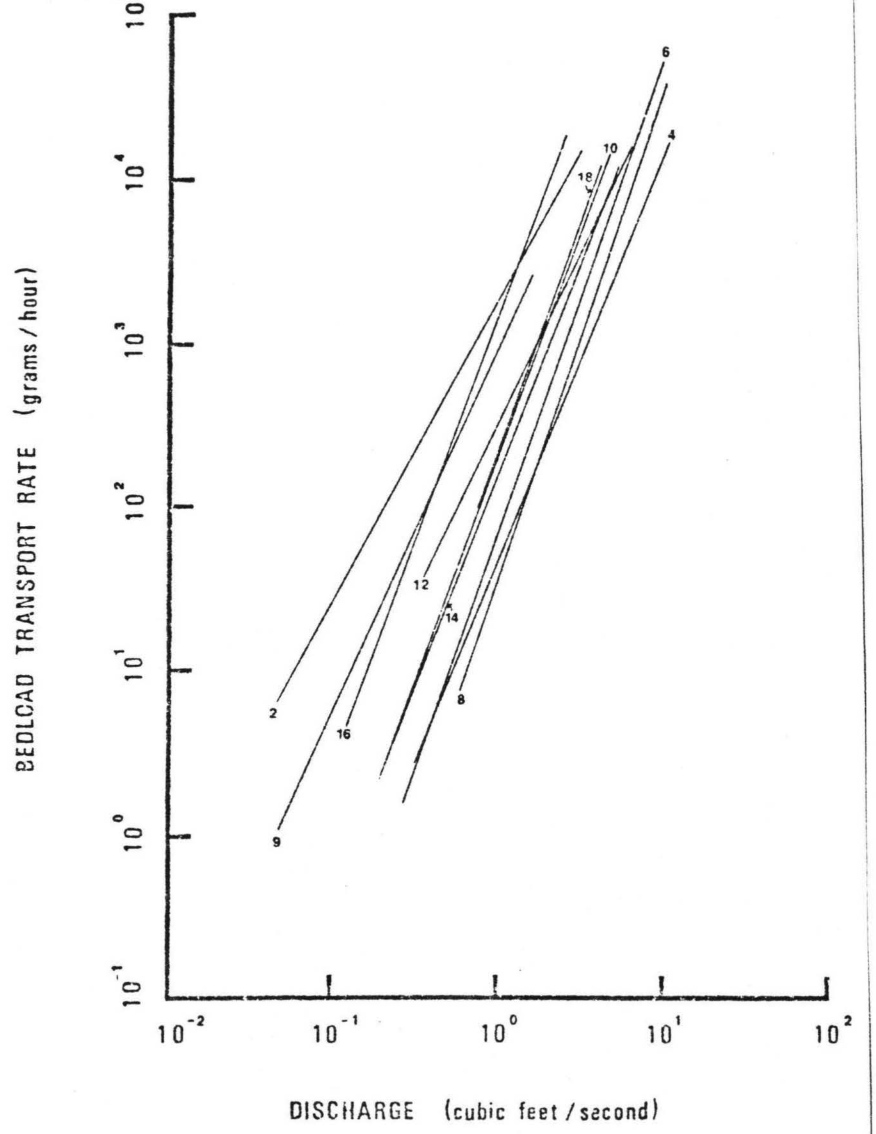


Figure 4. Bedload rating curves for the Horse Creek Subwatersheds for water years 1975 and 1976 combined.

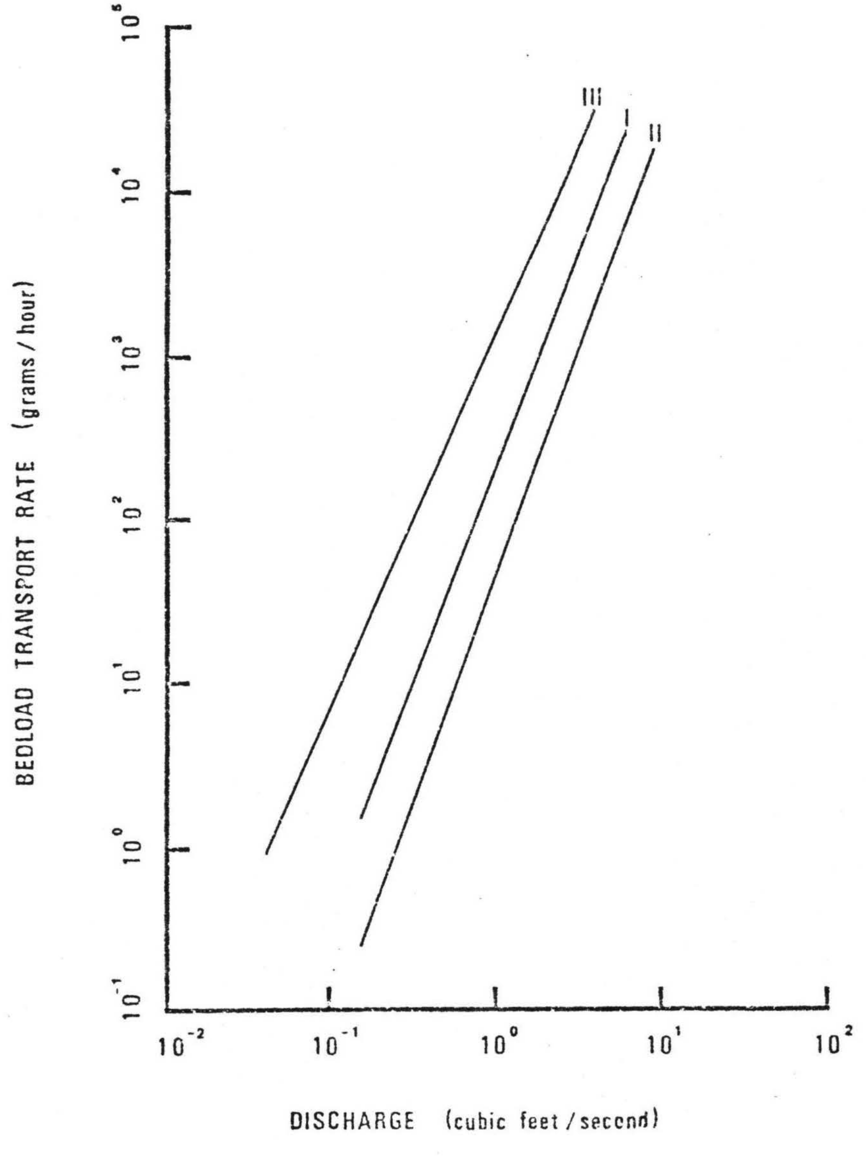


Figure 5. Bedload rating curves for the geomorphic groupings of the Horse Creek Subwatersheds.

Bedload transport rates were measured on the subwatersheds during the snowmelt period of 1977. These samples were collected for purposes of evaluating the previously developed rating curves. Although in 1977 the stream discharges were very low, bedload transport rates were in general agreement with what would have been predicted using the rating curve (Figure 6). Based on analysis of covariance, the bedload rating curves were similar with groups III (2, 9, and 16) and II (4, 6, and 8). For all three groups, the 1977 rating curves generally were steeper but with lower rates of transport over the range of 1977 discharges. The 1977 and 1975-76 rating curves for group I (10, 12, 14, and 18) were not statistically similar, having different slopes.

The data collected in 1977 were pooled with the previous data to develop three new rating curves using equation (2) (Table 13). Since these relationships are attempting to define the sedimentation processes for undisturbed drainages, the relationships should include annual variability due to changing sediment availability, channel hydraulics, etc. The effects of future management activities will be significant if they alter processes to a greater degree than annual variability.

Table 13. Regression coefficients and statistical information for the bedload rating curves for the geomorphic groupings of Horse Creek Subwatersheds for water years 1975, 1976, and 1977.

Group	Subwatershed	$\hat{\beta}_o$	$\hat{\beta}_1$	Standard Error	R^2	Significance
I	10,12,14,18	2.2095	2.7741	0.50	0.85	**[1/]
II	4, 6, 8	1.4942	2.8703	0.61	0.83	**
III	2, 9, 16	3.0949	2.3834	0.64	0.76	**

[1/] **Indicates significance at $\alpha = 0.01$.

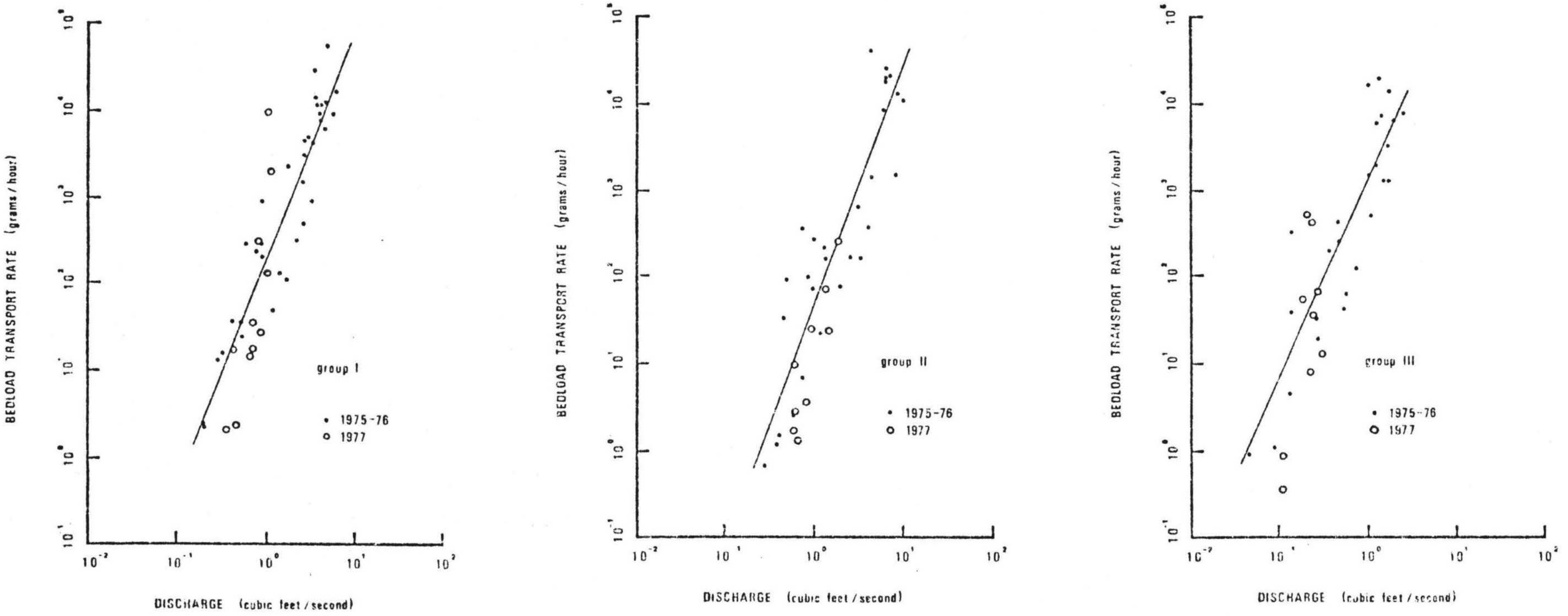


Figure 6. Bedload rating curves and individual data points for water years 1975, 1976, and 1977 for the geomorphic groupings of Horse Creek Subwatersheds.

Principal component analysis indicated that those geomorphic variables most useful in explaining differences between these ten subwatersheds were the lemniscate constant, basin circularity, texture ratio, stream length ratio, number of first order streams, mean length of first order streams, maximum length of the basin, perimeter length, relief, relief ratio, ruggedness number, and aspect. To determine if these characteristics influence the bedload rating curves, ass geomorphic characteristics were correlated with the regression coefficients for the respective rating curves. The regression coefficient estimate representing the intercept, $\hat{\beta}_o$, was negatively correlated with maximum width of the basin, perimeter length and area (Table 14). These variables are "size" descriptors of the subwatersheds. Total stream length was also negatively correlated with $\hat{\beta}_o$, however, total stream length is directly related to the watershed area. The correlation coefficient between total stream length and area was 0.81. The area variable was initially discarded from principal component analysis because it was strongly correlated with perimeter length. Thus, the ability of principal component analysis to select variables that have the most influence on the rating curves is questionable due in part to the discarding procedure. Generally, as watershed size increases, the transport rate, for a given discharge, decreases. This may be caused by shorter travel distances for bedload in smaller watersheds and a lower probability of being deposited or it may result from more rapid downcutting of the channel in smaller watersheds.

Watershed area was the single best predictor of $\hat{\beta}_o$ for these subwatersheds. This relationship, shown below, was highly significant ($\alpha = 0.01$).

$$\hat{\beta}_o = 3.3986 - 0.0054 \text{ Area (acres)} \qquad R^2 = 0.78$$

Standard error = 0.3101

Table 14. Correlation coefficients for the pairwise relationships between geomorphic variables and the regression coefficients for the bedload transport rating curves.

Estimated Regression Coefficient	Geomorphic Variables	Correlation Coefficient
$\hat{\beta}_o$	Maximum length	-0.8654
	Area	-0.8839
	Perimeter length	-0.8190
	Total stream length	-0.8149
$\hat{\beta}_1$	Relief ratio	-0.6841

The best correlation between the estimated regression coefficient for slope, $\hat{\beta}_1$, and any geomorphic variable was with the relief ratio (Table 14). This variable was selected by principal component analysis and had a high value for the third component. This relationship was significant ($\alpha = 0.05$) and may suggest that as the watersheds become steeper there is a reduction in the slope of the rating curves. It can be expressed as:

$$\hat{\beta}_1 = 4.8440 - 9.0101 \text{ Relief Ratio} \qquad R^2 = 0.47$$

Standard error = 0.3002

Megahan (1978) in his investigations of sediment transport in small forested watershed in central Idaho found an inverse relationship between stream channel gradient and the frequency of natural sediment traps in the stream channel. One would expect channel gradients to be steeper on watersheds with high relief ratios; thus, as the relief ratio increases the probability of bedload material being deposited behind natural traps may increase, resulting in a less steep bedload rating curve.

Other researches have related the delivery ratio for sediment to basin characteristics. Renfro (1972) has expressed the delivery ratio as a function of the relief length ratio of the basin. Williams and Berndt (1972) defined a power function between the delivery ratio and either basin area or channel gradient. Li and Simmons (1973) found this power function to be applicable to areas with similar hydrology and geology. Thus, watershed characteristics, especially size and slope descriptions, have been shown to regulate sediment transport processes.

SUSPENDED SEDIMENT

Sediment that is suspended or supported by the flow and transported outside of the bed layer is referred to as the suspended load. A portion of the suspended load is comprised of colloidal size particles that remain in suspension for a considerable period of time in the absence of turbulence. Material transported in suspension is influenced by stream velocity and particle characteristics. Concentrations of suspended material are also governed by the availability of particles for transport.

Benedict (1948) points out that the concentration of suspended sediment in any stream has no constant relationship to stage (stream depth) or a change in stage. He suggests that concentrations may also be governed by the intensity of precipitation or rate of snowmelt, vegetation cover, season, condition and kind of soil surface, topography, size of the stream, stability of the channel and the shape of the watershed. However, many researchers (Farnes 1975, Piest 1963) have found relationships between suspended sediment concentrations and stage or discharge. Typically, there is a noticeable "hysteresis effect" in any suspended sediment concentration-discharge relationship. For any given discharge, there is usually greater concentrations during the rising limb of the hydrograph (Nordin 1964, Walling 1977). Rosgen (1975) reported, for a north Idaho stream, the suspended sediment concentration peaked approximately two weeks prior to peak stream flow. This phenomenon may be due to a decrease in upstream sediment supply as peak flows are approached or a change in channel characteristics governing transport.

The relationship between suspended sediment concentration and discharge is usually not linear. Suspended sediment rating curves are usually expressed as a relationship between the common logarithms of suspended sediment concentration and discharge. Walling (1977) justifies this relationship in terms of data normality, the linearity of the relationship and the consideration of homoscedastisity. In many cases there is considerable scatter in this relationship. Walling (1977) found that individual rating curves developed for rising or falling discharge were considerably better for prediction purposes than a single rating curve.

Methods:

Suspended sediment concentrations were determined by filtering known volumes of stream water through a 0.45 micron filter. Based on the oven dry weight of the nonfilterable sediment the concentration in mg/l was calculated.

Sampling for suspended sediment commenced near the peak of the snowmelt hydrograph in 1975 and 1976 due to inaccessibility at earlier dates. Sampling frequency was biweekly during peak flows tapering off to monthly during low flow periods. One liter samples were collected above and below the sediment debris basins at the mouth of each subwatershed.

There was no determination of the percentage of organic matter in the suspended sediment; however, other researches (Doty and Hookano, Jr 1974) found that organic matter represented 10 percent of the total suspended sediment load for three small watersheds in northern Utah.

Analysis and Results:

Suspended sediment rating curves were developed for each subwatershed for 1975 and 1976 at the two sampling locations in each subwatershed using the same model (equation 1) used for the bedload rating curves. Analysis of covariance indicated that there was no statistical difference between the two sampling locations or between the two years of record, with two exceptions. Subwatershed 10 had statistically different rating curves for the two years and for subwatershed 4 the rating curves developed above and below the debris basins were slightly different. However, for purposes of uniformity in the methodology the data was pooled to generate a single rating curve for each subwatershed.

The suspended sediment rating curves for the ten subwatersheds are shown in Table 15 and Figure 7. The relationship between suspended sediment concentrations and discharge was significant ($\alpha = .01$) for all subwatersheds; however, there was a considerable amount of scatter as indexed by the relatively low coefficients of determination. Between watersheds there was considerable variability in these rating curves (Figure 7). For instance, at a discharge of one cubic foot per second, predicted concentrations range from 2.7 mg/1 for subwatershed 8 to 20.2 mg/1 for subwatershed 9.

Table 15. Regression coefficients and statistical information for the suspended sediment rating curves for the Horse Creek Subwatersheds.

Subwatershed	$\hat{\beta}_o$	$\hat{\beta}_1$	Standard Error	R^2	Significance
2	1.1962	0.6347	0.58	0.41	**[1]
4	0.4502	0.6057	0.55	0.33	**
6	0.5538	1.0431	0.41	0.64	**
8	0.4267	1.2791	0.28	0.67	**
9	1.3058	0.8180	0.52	0.47	**
10	0.9593	0.9535	0.49	0.58	**
12	0.5457	0.8952	0.53	0.48	**
14	0.6046	0.5912	0.61	0.28	**
16	1.2995	0.8752	0.64	0.44	**
18	0.6960	0.8727	0.46	0.40	**

[1] **Indicates significance at $\alpha = 0.01$.

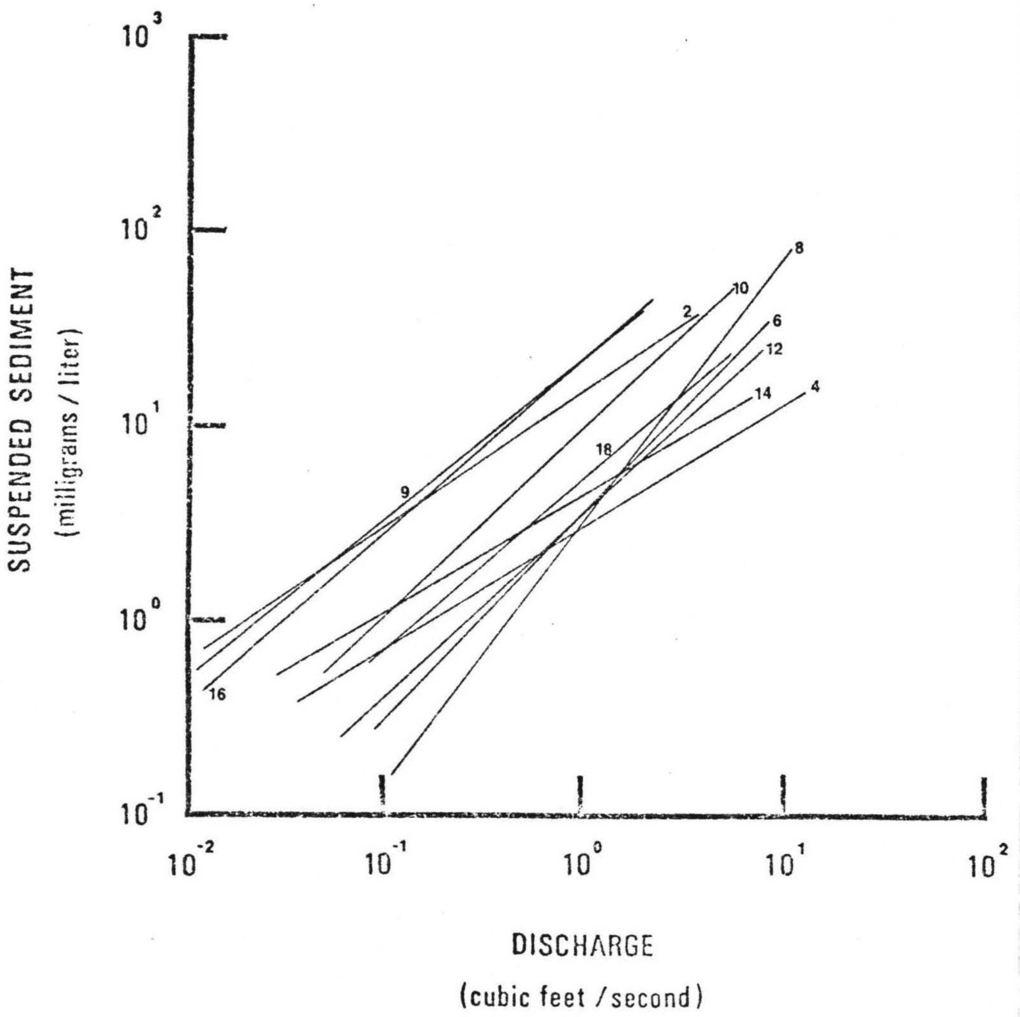


Figure 7. Suspended sediment rating curves for the Horse Creek Subwatersheds for water years 1975 and 1976.

These rating curves do not exhibit the grouping relative to the geomorphological classification from principal component analysis as did the bedload rating curves. However, there is one evident distinction. Subwatersheds 2, 9, and 16 (geomorphic group I) typically had higher concentrations of suspended sediment for a given discharge than the other subwatersheds.

Suspended sediment samples collected during water year 1977 were used to verify these rating curves. Water year 1977 had extremely low stream discharges with little variation between peak and low flows. As a result, suspended sediment concentrations were not significantly related to stream discharge. The water samples collected during water year 1977 generally had slightly higher concentrations of suspended sediment than predicted during high flows (Appendix 7). The data for the three water years were combined to generate rating curves incorporating annual variability (Appendix 7).

Correlation analysis was used to examine the pairwise relationships between the regression coefficients for these rating curves with all of the geomorphic variables of the subwatersheds (Table 16). The intercept, $\hat{\beta}_o$, was inversely related to three "size" characteristics: maximum width, perimeter length and area, and one stream variable, total stream length. However, total stream length is a function of watershed size, being directly correlated to area ($r = 0.8080$). These were the same geomorphic variables correlated with the $\hat{\beta}_o$ for the bedload regressions. Thus, for these subwatersheds, as watershed size increases there is a decrease in suspended sediment concentrations for a given discharge. Watershed area, A, was the best predictor of $\hat{\beta}_o$. This relationship can be expressed as:

$$\hat{\beta}_o = 1.3924 - 0.0028\,A \text{ (acres)} \qquad R^2 = 0.76$$

$$\text{standard error} = 0.16$$

Table 16. Correlation coefficients for the pairwise relationships between geomorphic variables and the regression coefficients for the suspended sediment rating curves.

Estimated Regression Coefficient	Geomorphic Variables	Correlation Coefficient
$\hat{\beta}_o$	Maximum width	-0.8435
	Perimeter length	-0.8189
	Area	-0.8718
	Total stream length	-0.8367
$\hat{\beta}_1$	Relief ratio	-0.7840

The estimated regression coefficient for slope, $\hat{\beta}_1$, was most strongly correlated with the relief ratio, Rh, for the subwatersheds. This inverse relationship indicates that as watersheds become steeper there is a reduction in the slope of the rating curve. The single best predictor of $\hat{\beta}_1$ was relief ratio. This relationship was significant at $\alpha = 0.01$ and can be expressed as:

$$\hat{\beta}_1 = 2.2896 - 5.6721\ R_h \qquad R^2 = 0.61$$

$$\text{standard error} = 0.22$$

TOTAL SEDIMENT YIELDS

Methods:

The USDA Forest Service has measured the annual sediment deposited in debris basins located at the mouth of each subwatershed since 1975 and for a few subwatersheds since 1974. Total volumes of sediment are measured during the early summer months using a sag tape cross sectioning technique. These debris basins were designed to capture the annual bedload production for the subwatersheds, although material transported in suspension may also be deposited. The volumes of ponded water in these basins is relatively small resulting in short detention times for streamflow entering the ponds.

During the summers of 1975 and 1976 core samples were taken of the sediment in the debris basins on subwatersheds 4, 6, 8, and 14. The particle size distribution and percentage of organic material was determined for each core sample. The data from the cores for each pond were averaged and used to reflect the general characteristics of the sediment deposited in the debris basins.

Analysis and Results:

The volumes of trapped sediment in the four debris basins for water years 1974, 1975, 1976, and 1977 exhibit considerable annual variation (Table 17). Much of this variability can be attributed to annual variations in the snowmelt hydrograph. The year of highest peak flow, 1976, produced the largest volumes of sediment, while in 1977 under drought conditions, very little sediment was transported from these subwatersheds. An additional cause of annual variability may be the result of mass wasting processes which may contribute sediment directly to the stream channel. No attempt was made during this study to establish the occurrence of these events. Sediment production from subwatersheds 10 and 16 were substantially greater than the other watersheds for water year 1975, which may have resulted from mass wasting processes.

Channel stability was evaluated using a methodology developed by USDA Forest Service hydrologists in Region 1 (USDA Forest Service 1975). Brooks (1978) indicated that most of the channel systems in the subwatersheds had similar stability ratings, with one exception. Channels in Subwatershed 16 were the most unstable, exhibiting characteristics that would indicate a high potential for large sediment yields. This subwatershed had the highest mean annual sediment production (yds^3/mi^2) and exhibited extremely high production during water year 1975.

Table 17. Total volumes of sediment (cubic yards) measured in the sediment catch basins for the Horse Creek Subwatersheds during water years 1974, 1975, 1976, and 1977.

Water Year	Subwatershed									
	2	4	6	8	9	10	12	14	16	18
1974	-	-	6.37	-	-	-	-	-	5.87	11.52
1975	7.08	10.04	4.66	10.44	3.55	24.06	9.90	3.37	27.69	10.93
1976	17.24	15.92	8.74	19.89	2.98	14.49	13.93	7.33	3.96	15.45
1977	1.59	4.69	1.10	4.31	0.83	1.85	1.67	5.29	0.87	3.57
Mean	8.64	10.21	5.22	11.54	2.45	13.47	8.50	5.33	9.60	10.37
Standard Deviation	7.94	5.62	3.22	7.85	1.43	11.14	6.25	1.98	12.24	4.95

Previous studies have shown a relationship between annual sediment production and annual water yields (Ursic and Dendy 1963). For water year 1976 there was a significant correlation between the cubic yards of sediment measured in the debris basins and the acre-feet of water yield (correlation coefficient = 0.69) as well as for the water years 1975, 1976, and 1977 (Figure 8). The combined relationship can be expressed as:

$$Y = 3.704 + 0.015X \qquad R^2 = 0.24$$

standard error = 7.18

where Y = annual deposited sediment (yd^3)

X = annual water yield (acre feet)

This regression was statistically improved by inclusion of either area or relief ratio as an additional independent variable. However, for the individual water years there was not a consistent relationship between annual sediment yields and either of these two geomorphic variables. Other researchers have shown a significant relationship between either area or relief ratio and annual sediment yields. Schumm (1954) expressed the logarithm of the annual sediment loss as a function of the relief ratio for small watersheds in the Colorado Plateau Province exhibiting distinctly different parent materials. This relationship was not evident for the Horse Creek Subwatersheds.

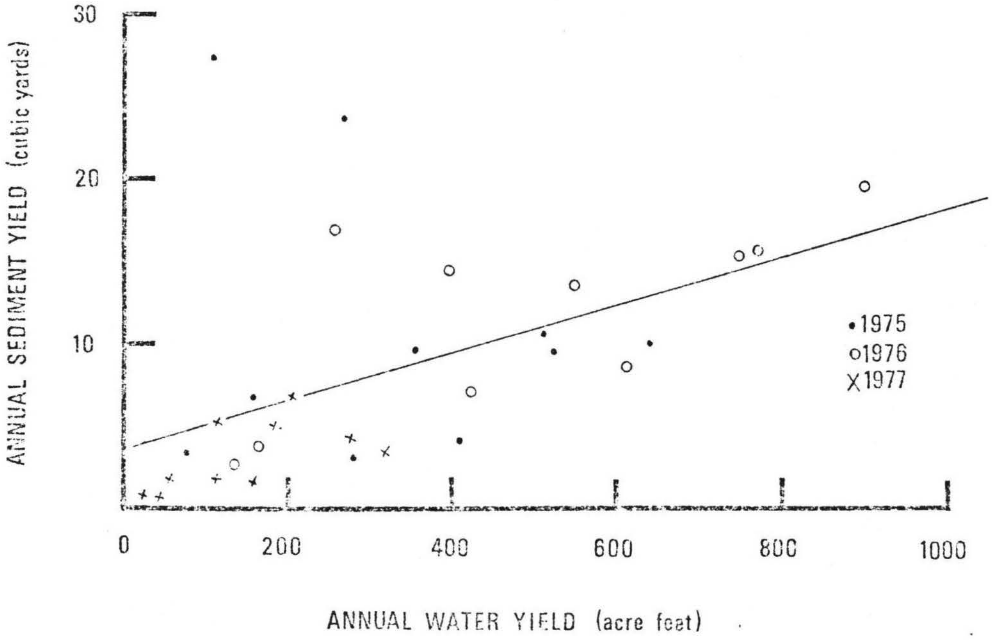


Figure 8. The relationship between annual water yield and annual sediment yield deposited in the debris basins for the Horse Creek Subwatersheds.

Total volumes of annual sediment production were predicted for subwatersheds 4, 6, 8, and 14 for water years 1975 and 1976 using the individual rating curves for suspended and bedload sediment (Table 18). Mean daily discharges were used in conjunction with the rating curves. These predicted volumes are probably underestimates of the actual volumes for suspended sediment. This results because the rating curves for suspended material were developed from data collected following the peak of the snowmelt hydrograph; thus, any hysteresis effect resulting in higher concentrations prior to the peak flow is not incorporated. Suspended and bedload samples are not mutually exclusive; therefore, predicted total volumes should be viewed as estimates.

Table 18. Predicted annual production (lbs.) of suspended and bedload sediment for selected Horse Creek Subwatersheds for water years 1975 and 1976.

Water year		Subwatershed 4	6	8	14
1975	Bedload	4,719	6,102	10,274	4,410
	Suspended	8,575	10,275	24,293	12,842
	TOTAL	13,294	16,377	34,567	17,252
1976	Bedload	6,413	7,444	10,393	6,193
	Suspended	11,542	13,009	26,803	5,963
	TOTAL	17,955	20,453	37,196	12,156

Sediment transported in suspension accounts for 49-74% of the annual production. Soils on these subwatersheds have fine textures with high proportions of silt and clay particles. Thus, sediment transport in suspension is the dominant process in Horse Creek. Both Megahan (1972) and Leaf (1966) found that for coarse textured soils, bedload transport was the major contributor to the annual sediment production.

The majority of sediment production occurs during the months of high flows resulting from snowmelt. The percentage of the total annual sediment production occurring during the three months of highest flows ranged from 91.0 to 98.9% for water years 1975 and 1976. Sediment production, especially bedload, is insignificant for the remainder of the water year.

The mean D_{50} of the core samples from the four debris basins ranged from 0.59 mm to 1.817 mm (Table 19). Appendix 8 shows the particle size distribution curves for these subwatersheds for water years 1975 and

1976. Sand particles (0.075 mm to 2 mm) accounted for 35 to 65% of the weight of the sediment for water year 1975 and 60 to 75% for water year 1976. Gravel size and larger particles (> 2.00 mm) accounted for 25 to 60%, and 25 to 35% of the sediment for water years 1975 and 1976, respectively. Silts and clay size particles (< 0.05 mm) are not present in significant proportions (< 5%) since they are carried in suspension and do not settle out rapidly. For each individual basin, above and below samples of suspended sediment concentrations were statistically similar, indicating a negligible trapping effect for suspended particles.

Table 19. Mean diameters (mm) for the cores of deposited sediment. Taken from the debris basins in 1975 and 1976.

	Subwatershed							
	4		6		8		14	
	1975	1976	1975	1976	1975	1976	1975	1976
$\overline{D}_e$	3.025	2.095	5.320	2.891	4.047	2.641	2.862	4.059
$\overline{D}_{90}$	4.632	3.154	7.256	4.363	5.742	3.831	4.901	6.547
$\overline{D}_{60}$	1.453	0.816	3.371	1.444	2.314	1.334	1.249	1.794
$\overline{D}_{50}$	1.053	0.589	2.613	1.002	1.817	1.046	0.762	1.242
$\overline{D}_{10}$	0.155	0.130	0.310	0.169	0.227	0.170	0.131	0.210
$\overline{D}_{60}/\overline{D}_{10}$	9.374	6.277	10.874	8.544	10.194	7.847	9.534	8.543

The mean percentage of organic matter in the debris basins ranged from 4.4% to 17.2% on a weight basis (Table 20). Subwatersheds 6 and 4 respectively had the lowest and highest percentage of organics for both water years.

Table 20. Mean and range of the percentage of organics for the core samples of sediment taken in the debris basins during 1975 and 1976.

	4		6		8		14	
	1975	1976	1975	1976	1975	1976	1975	1976
Mean	15.6	17.2	4.4	5.1	7.1	10.1	12.2	15.1
Range	0.2- 42.5	1.1- 42.6	0.2- 13.8	0.2- 13.3	0.3- 20.2	0.2 36.2	0.9- 29.6	0.9 -50.8

TRAP EFFICIENCY

Brune (1953) evaluated the trap efficiencies of storage reservoirs and related their efficiency to the ratio of the reservoir capacity to the annual inflow. Brune also considered the age of the reservoir, shape of the reservoir, type of outlet, size grading of the sediment, and the behavior of the fine sediments. However, for small basins in the mountainous west, there is a lack of information concerning trapping efficiency of debris basins.

Leaf (1966) evaluated the sediment yields from three high mountain watersheds in Colorado. Soils on these watersheds had a coarse texture with a very small proportion of silts or clays. In this instance, the debris basins virtually trapped all of the transported sediments.

In a study of sediment yields from fourteen small watersheds on the Idaho Batholith, Megahan (1972) suggests that the trapping efficiencies were at least 80%. These watersheds also had coarse textured soils with silt and clay contents of 10 and 5%, respectively.

The soils in Horse Creek are predominantly silt loams with relatively high fractions of silts and clays, approximately 40% and 20%, respectively. Fine particles transported in suspension account for the majority of the sediment production and are not efficiently trapped in these debris basins. However, these basins were designed to capture only bedload material.

Trap efficiency has been shown by Ward, Hoan, and Barfield (1977) to be a function of the particle size distribution of the transported sediment. In their studies, as the percentage of particles smaller than a diameter of 20 microns increased, the trap efficiency decreased. For the Horse Creek Subwatersheds the trap efficiencies for the total sediment yields are low because the majority of the total sediment production is fine material transported in suspension.

Methods:

Trap efficiencies were estimated by using suspended sediment rating curves for the two sampling locations; immediately above the debris basin and approximately thirty yards downstream from the debris basin outfall, at a stream stage measuring installation. However, the channel between outfall and the stream stage measuring installations was not lined on five of the streams which could result in stream degradation or aggradation and poor estimates of suspended sediment transported through the debris basin. Therefore, trap efficiencies were only calculated for the five debris basins with lined channels. There were no measurements taken of debris basin volume or retention times to aid in explaining variations between debris basins. Reported efficiencies are mean values for the five debris basins. Since the completion of this study the USDA

Forest Service has installed water samples at the stream stage measuring installations on selected subwatersheds which will enable a better determination of trap efficiencies.

Analysis and Results:

Results indicated that approximately 77% of the sediment transported in suspension is flushed through the debris basins. It was assumed that 100% of the bedload material was trapped. This results in a mean trap efficiency of 49% of the total sediment yield. Comparison of the predicted annual yields of bedload plus suspended sediment on a weight basis deposited in the debris basins with volumes of actual deposited sediment indicate a mean weight/volume relationship of 43.4 lb/ft^3. This relationship is for a mean organic content of 10.9%. This is in close agreement with the weigh/volume versus organic content relationship found by Megahan (1972) for deposited sediment in the Idaho Batholith.

CONCLUSIONS AND DISCUSSION

The use of principal component analysis on geomorphic characteristics of the Horse Creek Subwatersheds provided: 1) a method of selecting variables that were important in distinguishing between watersheds; 2) a method of grouping watersheds that were geomorphologically similar; and 3) a basis for selecting variables to be used in regression analysis to predict sedimentation characteristics.

Those geomorphic characteristics that PCA determined to be useful in evaluating differences between subwatersheds or as an aid to grouping similar subwatersheds were: maximum basin length, basin perimeter, lemniscate constant, basin circularity, relief ratio, ruggedness number, relief, texture ratio, stream length ratio, the number of first order streams, the mean length of first order streams and aspect.

The grouping of watersheds on the basis of component scores for the first two extracted components showed that subwatersheds in Horse Creek fell into three groups. The one possible exception to this, subwatershed two, had several unique properties and perhaps could have been dealt with separately.

Other researchers have used principal component analysis as an aid in grouping watersheds or in distinguishing important watershed characteristics. Doornkamp and King (1971) in their study of third order basins in Uganda applied a factor analysis procedure to 18 morphometric variables. They concluded that variables describing the size and dissection properties of the basins were the most important in accounting for the behavior of all the data. They used cluster analysis in conjunction with the factor analysis to group similar watersheds but did not relate basin groupings with hydrologic or sedimentation behavior.

Anderson (1966) used principal component analysis as a means of selecting important variables to be used in regression analysis for prediction of sediment yields from 23 small watersheds in California. The results of principal component analysis on thirty watershed variables lead to a regression relating rainfall, wildfire, roads, grassland, and runoff variables to total suspended sediment yields. Anderson used the results of a similar analysis for mapping the erosion potential of land in western Oregon (Anderson 1954).

Bedload transport and suspended sediment concentrations were both significantly related to stream discharge using the following model:

$$\log_{10} Y = \beta_o + \beta_1 \log_{10} X + \varepsilon$$

where: Y = bedload transport (gm/hr) or suspended sediment (mg/1)

X = stream discharge (cfs)

ε = error

Bedload rating curves were not significantly different between years even though water year 1977 was an unusually dry year resulting in record low flows. The rating curves for bedload transport were associated with a limited amount of scatter of the data points around the regression line as indexed by coefficients of determinations ranging from 0.68 to 0.97. The rating curves for suspended sediment concentration, although significant, were characterized by considerable scatter in the data about the regression line. Coefficients of determination varied from 0.28 to 0.67 for these watersheds. Suspended sediment concentrations can be influenced by extraneous sources of particulates such as pollen or dust. Rainfall events may have a negligible effect on discharge but may flush a considerable volume of fine particulates into the channel system. In April of 1977 the USDA Forest Service installed automatic water samplers at the mouth of selected subwatersheds in an attempt to improve the suspended sediment rating curves prior to any management activity in Horse Creek.

It is expected that shifts in these rating curves will be evident following road building or harvesting in these subwatersheds (Rosgen 1976, Farnes 1975). Thus, they provide a means of statistically evaluating the effects of management on sediment transport. Analysis of covariance between pre and post treatment rating curves can be used to evaluate the changes, if any in these rating curves.

The D_{50} for the bedload samples indicate that most of the sediment transported is sand size particles or larger. The median diameter generally increased as discharge increased. The percentage of organic material transported as bedload was inversely proportional to discharge. The percentage of organics during low flows was as high as 64% and may indicate a substantial loss of nutrients from the subwatersheds.

The bedload rating curves were similar for the subwatersheds within each geomorphic group defined by PCA. Rating curves for suspended sediment were similar for one geomorphic grouping of subwatersheds. The remainder of the rating curves exhibited considerable overlapping. Therefore, suspended sediment rating curves were not pooled for their respective geomorphic group.

The area and relief ration of the subwatersheds were the best predictors of the estimated regression coefficients, β_0 and β_1, respectively, for both the bedload and suspended sediment rating curves. As the area increased the value of the intercept decreased and as the relief ratio increased the slope of the rating curve decreased. These relationships are apparent for the relatively homogeneous Horse Creek Subwatersheds but have not been verified on larger drainages or on different geologic types. Therefore, extrapolation of these relationships should be done with caution.

Annual sediment yields for bedload and suspended load can be predicted for these watersheds by use of the developed rating curves. Annual yields for primarily bedload were also measured in the debris basins of each subwatershed. Annual yields measured in the debris basins varied considerably from year to year in relation to the annual water yield for the subwatersheds. Annual yields of trapped sediment ranged for 2.75 to 253.18 yd^3/mi^2 (mean = 34.36 yd^3/mi^2). This is similar to yields from undisturbed forested watersheds with coarse soils in Colorado, (Leaf 1966) and central Idaho (Megahan 1972) where yields range from 0.3 to 20.5 yd^3/mi^2 and 4.5 to 33.8 yd^3/mi^2, respectively. However, in Horse Creek the majority of sediment is transported in suspension and accounts for over 60% of the annual sediment yield. Approximately 23% of the sediment transported in suspension is deposited in the debris basins. With this consideration, the Horse Creek Subwatersheds, with a large percentage of silt and clay in their soils, have much higher annual sediment productions than those reported by Leaf and Megahan.

Inherent Watershed Stability, an index developed by personnel on the Clearwater National Forest, was not an important variable on any component in PCA. It did not significantly correlate with the regression coefficients for the rating curves nor with annual sediment yields. Thus, there is some doubt to this index's applicability for characterizing sedimentation from undisturbed watersheds. It may be a useful planning concept and with refinement, may become more useful in evaluation of undisturbed watersheds or treatments effects.

WATER CHEMISTRY

The sources of dissolved nutrients to stream water are the atmosphere; precipitation, absorption of gases, and dry fallout; geologic weathering and biological decomposition. Supply rates of the various ions vary temporally and spacially as precipitation and temperature regimes change. Precipitation and temperature influence the direct supply of many nutrients to streams and the nutrient cycling in the watershed by regulating bacterial activity, decomposition and geologic weathering.

The geology and soil type of the site have a dominant effect on the concentrations of the various ions. The release of nutrients in weathering, weathering rates, and the absorption properties of the soil mantle are all largely determined by the underlying parent material. The rate of supply to the stream of a specific ion is then a function of its supply rate in the weathering of the soil-parent material-organic matter complex and its ability to be transported via subsurface flow to the channel.

The concentration of a specific ion in the stream water is not only a function of the supply rate to the stream but also the stream discharge. For a constant supply rate, concentration is inversely related to discharge. Hem (1975) expressed this dilution effect in the following equation:

$$Y = \beta X^n \qquad (1)$$

where Y = concentration of a specific ion

X = stream discharge

β, n = constants

This equation can be expressed in a linear form regression equation by logarithmic transformation.

$$\log_{10} Y = \beta_0 + \beta_1 \log_{10} X + \varepsilon \qquad (2)$$

where β_0, β_1 = regression coefficients

ε = error

Methods:

During 1975, 1976 and 1977, one liter stream water samples were periodically collected at two locations at the mouths of each subwatershed; immediately above and below the sediment debris basins. Samples were collected twice a week during spring and early summer snowmelt flows and monthly during the remainder of the year.

Field determinations were made of stream temperature, pH, specific conductivity and alkalinity. Samples were cooled and transported to the University of Idaho where determinations were made of pH, specific conductance, alkalinity, magnesium, calcium, sodium, nitrate, phosphate and sulfate using approved methods (Standard Methods, 1971 and EPA, 1974). Nitrate, phosphate and sulfate concentrations were not made for samples collected in 1977.

The relationship between stream discharge and water chemistry was determined using the regression model given as equation (2). These "rating curves" were compared between sampling years 1975-1976 and for the drought year of 1977. A correlation analysis was performed between the geomorphic characteristics of the subwatersheds and the regression coefficients for the individual rating curves.

Analysis and Results:

The tributaries to the Main Fork of Horse Creek are well shaded by streamside vegetation. In addition, there is a variable amount of topographic shading predominantly affecting the lower reaches of the tributaries. Peak summertime stream temperatures are approximately 15°C. Winter minimum temperatures are often slightly below freezing. No analysis was performed on the stream temperature data. Temperature was measured since it influences the concentration of dissolved gases and to provide base line data. Stream temperatures may increase significantly following harvesting of those southern exposure subwatersheds.

The pH of the Horse Creek streams ranged from 6.1 to 8.8 units in 1975 and 1976 and 5.6 to 7.9 units in 1977. Generally the streams were slightly acidic. Stream discharge had a significant effect on pH. As stream discharge increased the pH of the streams decreased slightly. The three smallest subwatersheds, 2, 9 and 16, always had the lowest pH for similar discharges from the subwatersheds.

The nitrate nitrogen, NO_3-N, concentrations of the streams draining the Horse Creek Subwatersheds were very low. Most of the samples had concentrations below 0.1 mg/l NO_3-N. There were few samples with higher concentrations. The highest concentration measured was 0.636 mg/l NO_3-N. Due to the large number of samples with concentrations below accurate detection limits, no attempt was made to relate stream discharge with concentration, nor were any comparisons made between subwatersheds or between sampling years.

The phosphate phosphorus, PO_4-P, concentrations ranged from .001 to 0.076 mg/l. The concentration of PO_4-P in the streams was not statistically related to stream discharge. Phosphate phosphorus concentrations were slightly greater for most streams during 1975, a year of lower stream discharge than 1976 (Table 21). The stream draining Subwatershed 2 had concentrations substantially less than the others, which may be due to a change in geology or soil type.

The sulfate, SO_4^{++}, concentrations ranged from 1.11 to 6.00 mg/1. In four of the ten subwatersheds, the sulfate concentrations were inversely related to stream discharge and these relationships were similar for 1975 and 1976 (Table 22). The mean concentrations for the ten subwatersheds (Table 23) were negatively correlated ($\alpha = 0.05$) with several watershed size descriptors; maximum basin length, basin perimeter length, and basin area. The smaller subwatersheds exhibited higher sulface concentrations.

The alkalinity of these streams is due predominately to the presence of the bicarbonate ion since pH is usually below 8.3. Alkalinity, expressed as mg/1 of $CaCO_3$, ranged from 9.56 to 30.50. Alkalinity increased as stream discharge decreased during all three sampling years (Tables 24 and 25). During 1977 this relationship was substantially different. The alkalinity concentrations were greater during 1977 for similar stream discharge than in 1975 and 1976.

The regression coefficients for alkalinity rating curves were correlated with geomorphic characteristics of the subwatersheds. $\hat{\beta}_0$ was best correlated with the lemniscate constant, a shape characteristic ($R = -0.59$, $\alpha = 0.1$) and $\hat{\beta}_1$ was best correlated with the relief ratio ($R = 0.89$, $\alpha = 0.01$).

Table 21. Average phosphate phosphorus, PO_4-P, concentrations for the ten Horse Creek Subwatersheds in 1975 and 1976.

	Subwatershed									
	2	4	6	8	9	10	12	14	16	18
1975 Average mg/l	0.009	0.026	0.016	0.030	0.027	0.046	0.028	0.024	0.028	0.034
1976 Average mg/l	0.009	0.017	0.017	0.017	0.020	0.030	0.024	0.026	0.022	0.028

Table 22. Regression coefficents and statistical information for the sulfate rating curves for the Horse Creek Subwatersheds in 1975 and 1976 (significance levels are +, $\alpha = 0.1$, *, $\alpha = 0.05$, **, $\alpha = 0.01$).

Subwatershed	$\hat{\beta}_0$	$\hat{\beta}_1$	Standard Error	R^2	Significance
2	0.3053	-0.0451	0.086	0.15	*
4	0.2853	-0.0589	0.106	0.13	*
8	0.2589	-0.0585	0.093	0.09	+
9	0.2427	-0.0984	0.169	0.12	*

Table 23. Means and standard deviations of sulfate concentrations (mg/l) for the Horse Creek Subwatersheds in 1975 and 1976.

	Subwatershed									
	2	4	6	8	9	10	12	14	16	18
Mean	2.14	1.96	1.86	1.78	2.09	2.00	1.91	2.19	2.19	2.24
Standard Deviation	1.23	1.29	1.29	1.25	1.50	1.20	1.29	1.35	1.20	1.29

Table 24. Regression coeffiicents and statistical information for the alkalinity rating curves for the Horse Creek Subwatersheds in 1975 and 1976 (significance levels are +, $\alpha = 0.1$, *, $\alpha = 0.05$, **, $\alpha = 0.01$).

Subwatershed	$\hat{\beta}_0$	$\hat{\beta}_1$	Standard Error	R^2	Significance
2	1.0850	-0.0590	0.080	0.25	**
4	1.1520	-0.0968	0.063	0.53	**
6	1.2062	-0.1701	0.075	0.60	**
8	1.2629	-0.1949	0.037	0.88	**
9	1.0752	-0.1452	0.060	0.70	**
10	1.2510	-0.1472	0.050	0.77	**
12	1.3100	-0.1528	0.049	0.77	**
14	1.1626	-0.1296	0.058	0.67	**
16	1.1209	-0.1090	0.048	0.70	**
18	1.1610	-0.1668	0.086	0.43	**

Table 25. Regression coefficients and statistical information for the alkalinity rating curves for the Horse Creek Subwatersheds in 1977 (significance levels are +, $\alpha = 0.1$, *, $\alpha = 0.05$, **, $\alpha = 0.01$).

Subwatershed	$\hat{\beta}_0$	$\hat{\beta}_1$	Standard Error	R^2	Significance
2	1.0054	-0.1622	0.110	0.36	*
4	1.1408	-0.2261	0.085	0.56	**
6	1.1604	-0.2867	0.088	0.54	**
8	1.2090	-0.3187	0.081	0.58	**
9	1.0661	-0.1607	0.114	0.28	*
10	1.1450	-0.2763	0.099	0.48	**
12	1.2257	-0.2905	0.064	0.68	**
14	1.0701	-0.2823	0.087	0.70	**
16	0.9704	-0.2758	0.073	0.67	**
18	1.1055	-0.3857	0.109	0.43	**

The concentrations of the calcium ion in samples collected in 1975 and 1976 ranged from 0.36 to 4.00 mg/l. Calcium concentrations were inversely related to stream discharge (Table 26). During the drought of 1977 the rating curves changed significantly (Table 27). For example, at a discharge of 1.0 cfs the average concentration of calcium for the ten subwatersheds in 1977 was 4.7 times as great as in 1975-1976. The three smallest watersheds, 2, 9 and 16, showed the largest increases during the drought of 1977. The average increase in concentration for these three watersheds was 7.2 times the 1975-1976 concentrations at a discharge of 1.0 cfs.

For 1975-1976, the $\hat{\beta}_0$ coefficient for the rating curves was significantly related to the lemniscate constant ($R = -0.69$, $\alpha = 0.05$) and the shape factor ($R = -0.66$, $\alpha = 0.05$). The slope coefficient, $\hat{\beta}_1$, was best correlated with the relief ratio ($R = 0.71$, $\alpha = 0.05$).

The concentrations of the magnesium ion in the Horse Creek samples ranged from 0.22 to 3.39 mg/l in 1975 and 1976. Concentrations were inversely related to stream discharge (Table 28). In 1977, the concentrations of magnesium were not significantly related to discharge for six of the subwatersheds (Table 29) and the concentrations were similar to those measured the previous two years.

The intercept coefficient, $\hat{\beta}_0$, was not significantly related to any of the geomorphic variables; however, $\hat{\beta}_1$, was related to the relief ratio of the subwatersheds ($R = 0.91$, $\alpha = 0.01$).

Table 26. Regression coefficients and statistical information for the calcium ion rating curves for the Horse Creek Subwatersheds in 1975 and 1976 (significance levels are *, α = 0.05, **, α =0.01, NS = not significant).

Subwatershed	$\hat{\beta}_0$	$\hat{\beta}_1$	Standard Error	R^2	Significance	Standard Deviation	Mean
2					NS	0.24	0.1922
4	-0.0537	-0.0947	0.150	0.16	**		
6	0.0015	-0.2673	0.159	0.45	**		
8	0.1069	-0.2392	0.154	0.39	**		
9	-0.1871	-0.1629	0.142	0.32	**		
10	0.0870	-0.1596	0.139	0.34	**		
12	0.1400	-0.2369	0.157	0.44	**		
14	-0.0540	-0.2454	0.145	0.54	**		
16	-0.0980	-0.2000	0.145	0.47	**		
18	-0.0040	-0.2645	0.167	0.33	**		

Table 27. Regression coefficients and statistical information for the calcium ion rating curves for the Horse Creek Subwatersheds in 1977 (significance levels are *, α = 0.05, **, α = 0.01, NS - not significant).

Subwatershed	$\hat{\beta}_0$	$\hat{\beta}_1$	Standard Error	R^2	Significance	Standard Deviation	Mean
2					NS	0.2985	0.6588
4					NS	0.2372	0.5655
6					NS	0.1142	0.6874
8					NS	0.1087	0.7342
9					NS	0.1039	0.6646
10	0.6273	-0.1321	0.050	0.48			
12					NS	0.1470	0.7866
14	0.4768	-0.2113	0.078	0.58	**		
16					NS	0.2590	0.7770
18	0.5042	-0.2743	0.084	0.40			

Table 28. Regression coefficients and statistical information for the magnesium ion rating curves for the Horse Creek Subwatersheds in 1975 and 1976 (significant levels are +, $\alpha = 0.1$, *, $\alpha = 0.05$, **, $\alpha = 0.01$).

Subwatershed	$\hat{\beta}_0$	$\hat{\beta}_1$	Standard Error	R^2	Significance
2	-0.2647	-0.0754	0.138	0.16	**
4	-0.2586	-0.1038	0.211	0.10	**
6	-0.1424	-0.2066	0.126	0.43	**
8	-0.1109	-0.2059	0.147	0.34	**
9	-0.4055	-0.1683	0.133	0.38	**
10	-0.1635	-0.1598	0.140	0.34	**
12	-0.0125	-0.1781	0.113	0.46	**
14	-0.2568	-0.1003	0.137	0.18	**
16	-0.1693	-0.0848	0.097	0.26	**
18	-0.2977	-0.1802	0.197	0.14	**

Table 29. Regression coefficients and statistical information for the magnesium ion rating curves for the Horse Creek Subwatersheds in 1977 (significance levels are *, $\alpha = 0.05$, **, $\alpha = 0.01$, NS = not significant).

Subwatershed	$\hat{\beta}_0$	$\hat{\beta}_1$	Standard Error	R^2	Significance	Standard Deviation	Mean
2					NS	0.14	-0.1545
4					NS	0.29	-0.3139
6	-0.1570	-0.1974	0.052	0.58			
8	-0.1331	-0.2182	0.100	0.28			
9					NS	0.12	-0.1348
10	-0.2422	-0.2049	0.045	0.74	**		
12					NS	0.14	-0.0610
14	-0.2932	-0.2065	0.053	0.76	**		
16					NS	0.06	-0.0326
18					NS	0.09	-0.2584

The concentrations of the potassium ion ranged from 0.53 to 1.75 mg/1 in 1975 and 1976. Concentrations were inversely related to stream discharge (Table 30). During 1977, five of the subwatersheds exhibited significant inverse relationships between stream discharge and potassium concentrations (Table 31). The concentrations were slightly higher during this drought year. For example, at a discharge of one cfs, concentrations were approximately 25 percent higher during 1977.

The intercept coefficient of the potassium rating curves, $\hat{\beta}_0$, was significantly related to the relief of the subwatershed ($R = 0.61$, $\alpha = 0.1$) and the slope coefficient, $\hat{\beta}_1$, was significantly related to the watershed relief ratio ($R = 0.60$, $\alpha = 0.10$).

The sodium ion concentrations in the Horse Creek streams ranged from 1.52 to 4.74 mg/1 in 1975 and 1976. The concentrations were inversely related to stream discharge (Table 32). In 1977, this relationship was not statistically evident in four of the streams (Table 33). The concentrations of sodium during 1977 remained similar to 1975-1976 levels, despite much lower discharges. Only in the three smallest watersheds, 2, 9 and 16, did concentrations noticeably increase, approximately 33 percent.

The intercept coefficient of the 1975-1976 rating curves was best correlated with the lemniscate constant ($R = -0.80$, $\alpha = 0.01$). The slope gradient, $\hat{\beta}_1$, was best correlated to the watersheds drainage density ($R = 0.68$, $\alpha = 0.05$).

Table 30. Regression coefficients and statistical information for the potassium ion rating curves for the Horse Creek Subwatersheds in 1975 and 1976 (significance levels are +, α = 0.1, *, α = 0.05, **, α = 0.01).

Subwatershed	$\hat{\beta}_0$	$\hat{\beta}_1$	Standard Error	R^2	Significance	Standard Deviation	Mean
2	0.0007	-0.0421	0.066	0.20	**		
4				NS		0.15	0.0340
6	-0.0199	-0.0886	0.068	0.33	**		
8	-0.0054	-0.0922	0.061	0.37	**		
9	-0.0513	-0.0942	0.075	0.38	**		
10	0.0008	-0.0721	0.058	0.38	**		
12	0.0074	-0.1557	0.172	0.22	**		
14	-0.0044	-0.0494	0.054	0.25	**		
16	-0.0107	-0.0387	0.063	0.15	**		
18	-0.0578	-0.1293	0.076	0.37	**		

Table 31. Regression coefficients and statistical information for the potassium ion rating curves for the Horse Creek Subwatersheds in 1977 (significance levels are *, α = 0.05, **, α = 0.01, NS - not significant).

Subwatershed	$\hat{\beta}_0$	$\hat{\beta}_1$	Standard Error	R^2	Significance	Standard Deviation	Mean
2					NS	0.11	0.1551
4	-0.0429	-0.2073	0.090	0.41	*		
6	-0.0603	-0.1335	0.053	0.36	*		
8					NS	0.07	0.1313
9					NS	0.06	0.1512
10	0.0287	-0.1373	0.052	0.48	**		
12					NS	0.12	0.1083
14	0.0695	-0.0749	0.044	0.34	*		
16					NS	0.06	0.1955
18	-0.0578	-0.1047	0.039	0.30	*		

Table 32. Regression coefficients and statistical information for the sodium ion rating curves for the Horse Creek Subwatersheds in 1975 and 1976 (significance levels are +, $\alpha = 0.1$, *, $\alpha = 0.05$, **, $\alpha = 0.01$).

Subwatershed	$\hat{\beta}_0$	$\hat{\beta}_1$	Standard Error	R^2	Significance
2	0.3157	-0.0997	0.114	0.32	**
4	0.4273	-0.0634	0.137	0.09	+
6	0.3732	-0.1285	0.080	0.43	**
8	0.4334	-0.1424	0.042	0.75	**
9	0.2727	-0.1603	0.054	0.78	**
10	0.4159	-0.1226	0.048	0.72	**
12	0.4449	-0.1148	0.045	0.69	**
14	0.3887	-0.1013	0.052	0.60	**
16	0.3581	-0.0566	0.052	0.35	**
18	0.4008	-0.1387	0.074	0.41	**

Table 33. Regression coefficients and statistical information for the sodium ion rating curves for the Horse Creek Subwatersheds in 1977 (significance levels are *, $\alpha = 0.05$, **, $\alpha = 0.01$, **, NS = not significant).

Subwatershed	$\hat{\beta}_0$	$\hat{\beta}_1$	Standard Error	R^2	Significance	Standard Deviation	Mean
2					NS	0.12	0.4459
4	0.1217	-0.3569	0.205	0.27	*		
6	0.3832	-0.1730	0.068	0.36	*		
8	0.3802	-0.2473	0.041	0.79	**		
9					NS	0.08	0.4912
10	0.3525	-0.1915	0.046	0.71	**		
12					NS	0.15	0.4563
14	0.3630	-0.1217	0.033	0.74	**		
16					**	0.13	0.4908
18	0.3512	-0.2060	0.043	0.65	**		

The specific conductance of the Horse Creek streams ranged from 15 to 35 micromhos per centimeter ($25^{\circ}C$) for 1975 and 1976. Conductance was inversely related to stream discharge (Table 34). In 1977 this inverse relationship was also evident (Table 35) but the rating curves had significantly changed. During the drought of 1977 the conductance values were higher, ranging from 17 to 71 micromhos per centimeter. This increase in conductivity is only partially explained by the lower stream discharges. For example, during the lowest discharge sampled in 1977 in Subwatershed 6, the predicted conductivity was 47.8 micromhos per centimeter. Extrapolating the 1975-1976 rating curves to the same discharge results in a prediction of 43 micromhos per centimeter. During peak flows in 1977 the levels of conductance were generally lower than would have been predicted by the 1975-1976 rating curves. Thus the slopes of the rating curves change appreciably during the drought.

The rating curve coefficients were significantly correlated to several of the geomorphic characteristics of the subwatersheds. The intercept coefficient, $\hat{\beta}_0$, was significantly related to the lemniscate constant (1975-1976 $R = -0.62$, $\alpha = 0.1$, 1977 $R = 0.65$, $\alpha = 0.05$) and the relief ratio (1975-1976 $R = -0.57$, $\alpha = 0.1$; 1977 $R = -0.74$, $\alpha = 0.05$). The slope coefficient, $\hat{\beta}_1$, was correlated with the relief ratio (1975-1976 $R = 0.79$, $\alpha = 0.01$; 1977 $R = 0.59$, $\alpha = 0.1$).

Table 34. Regression coefficients and statistical information for the specific conductivity rating curves for the Horse Creek Subwatersheds in 1975 and 1976 (significance levels are *, $\alpha = 0.05$, **, $\alpha = 0.01$, NS = not significant).

Subwatershed	$\hat{\beta}_0$	$\hat{\beta}_1$	Standard Error	R^2	Significance
2	1.2990	-0.0880	0.092	0.36	**
4	1.3840	-0.0999	0.080	0.43	**
6	1.4437	-0.1883	0.054	0.78	**
8	1.5131	-0.2180	0.054	0.81	**
9	1.2984	-0.1621	0.078	0.63	**
10	1.4906	-0.1468	0.071	0.63	**
12	1.5509	-0.1793	0.066	0.72	**
14	1.4089	-0.1561	0.069	0.67	**
16	1.3713	-0.1298	0.071	0.61	**
18	1.4104	-0.2533	0.094	0.59	**

Table 35. Regression coefficients and statistical information for the specific conductivity rating curves for the Horse Creek Subwatersheds in 1977 (significance levels are *, $\alpha = 0.05$, **, $\alpha = 0.01$, NS = not significant).

Subwatershed	$\hat{\beta}_0$	$\hat{\beta}_1$	Standard Error	R^2	Significance
2	1.0691	-0.2424	0.093	0.66	**
4	1.2978	-0.2682	0.068	0.74	**
6	1.3627	-0.3139	0.067	0.71	**
8	1.4598	-0.2833	0.077	0.55	**
9	1.1748	-0.2205	0.072	0.69	**
10	1.3552	-0.2928	0.079	0.63	**
12	1.4297	-0.3366	0.055	0.80	**
14	1.2918	-0.2691	0.067	0.78	**
16	1.2549	-0.2362	0.060	0.70	**
18	1.3049	-0.4221	0.078	0.65	**

CONCLUSIONS AND DISCUSSION

The streams draining the Horse Creek Subwatersheds have low concentrations of dissolved chemicals (Table 36). Buettner and Falter (1978) did a chemical analysis of selected streams in the Idaho Primitive Area. Two of the streams, Beaver and Snowslide Creeks, drain watersheds underlain with Precambrian Belt series formations, similar to those of Horse Creek. They found larger concentrations of dissolved chemicals in stream samples collected at the mouths of the watersheds as compared to samples at the headwaters of the streams. The chemical concentrations in the headwater samples were similar to those found in the Horse Creek streams.

As stream discharge increases the concentrations or levels of many of the water quality parameters decrease due to dilution. In the Horse Creek streams, pH, sulfates, alkalinity, calcium, magnesium, potassium, sodium and specific conductivity were inversely related to stream discharge using the following regression model:

$$\log_{10} Y = \beta_0 + \beta_1 \log_{10} X + \varepsilon$$

where Y = concentration or level of the chemical parameter
X = stream discharge (cfs)
ε = error

The phosphate phosphorus concentrations were not related to stream discharge using this model. Nitrate nitrogen concentrations were frequently below accurate detection limits and therefore not modeled.

During the drought of 1977 stream discharges were substantially less than during the previous two years of sampling. Higher concentrations or levels of the water chemistry parameter were measured during 1977 which

Table 36. The range of chemical constituent concentrations in samples collected in the Horse Creek Subwatersheds during 1975, 1976 and 1977. 1/

	pH	NO_4-N mg/l	PO_4-P mg/l	SO_4 mg/l	HCO_3 mg/l $CaCO_3$	Ca mg/l	Mg mg/l	K mg/l	Na mg/l	S.C. 2/ μmhos/cm
Lowest value	5.6	<0.100	0.001	1.11	9.56	0.36	0.08	0.53	0.82	15
Highest value	8.8	0.636	0.076	6.00	45.3	9.92	3.61	3.02	8.93	71

[1] Nitrate nitrogen, phosphate phosphorus and sulfate concentrations were not measured in 1977.

[2] S.C. = specific conductance.

was partially due to decreased flow; however, the regression models (rating curves) developed for 1977 were significantly different for many of the parameters. The alkalinity, calcium, sodium, potassium and specific conductance rating curves exhibited substantial shifts during the drought year. Especially at lower flows, the concentrations or levels of these parameters were higher during 1977 than would have been predicted using the 1975-1976 rating curves. The largest shifts in the rating curves generally were those for the three smallest subwatersheds, (group III in the principal component analysis) 2, 9 and 16.

The relationship between stream discharge and the water chemistry parameters were not similar for all of the subwatersheds. Especially evident was the fact that subwatersheds 2, 9 and 16 had similar rating curves, but were quite different than the rating curves for the other subwatersheds. Streams in 2, 9 and 16 had higher concentrations of sulfate, alkalinity, calcium and magnesium, higher specific conductance, and lower pH than streams in the other subwatersheds for the same stream discharge.

Several studies have shown that streams draining similar geologic types have similar water chemistry (Snyder, 1976; Buettner and Falter, 1977). However, other geomorphic characteristics of watersheds also influence water chemistry and the relationship between stream discharge and water chemistry. In the Horse Creek Subwatersheds, the mean sulfate concentration was significantly inversely correlated with watershed size parameters; maximum basin length, perimeter length, and area. Two of these characteristics, maximum basin length and perimeter length, were extracted in principal component analysis. They were extracted in the second component, the area-slope component. The smaller subwatersheds typically had the highest sulfate concentrations. This may be caused by lower stream discharges resulting in less dilution of this anion. These three subwatersheds produce less water per unit area than the adjacent subwatersheds. Thus, assuming a constant supply of sulfate per unit area, there is less water to dilute the concentration on these three subwatersheds.

The rating curves for alkalinity, calcium, sodium and conductivity are influenced by the shape of the subwatershed. The intercept coefficients, $\hat{\beta}_0$, were inversely correlated with the lemniscate constant. The lemniscate constant was extracted in the first component of principal component analysis. Variables in this component described the shape-dissection properties of the subwatersheds. The lemniscate constant (K) is a function of the maximum basin length (L_b) and the subwatershed area (A).

$$K = \frac{L_b^2 \pi}{4A}$$

The slope coefficients, $\hat{\beta}_1$, for the alkalinity, calcium, magnesium, potassium and conductivity rating curves were significantly and positively correlated with the subwatershed relief ratio (R_h). The relief ratio is the total basin relief divided by the maximum length of the basin and is an index of the steepness of the basin.

Those subwatersheds with the greater lemniscate constants and the greater relief ratios, subwatersheds 2, 9 and 16, had lower concentrations of alkalinity, calcium and sodium and lower specific conductivities. These subwatersheds did not exhibit as great a change in water chemistry through their range of discharge as the others. Potassium and magnesium concentrations in subwatersheds 2, 9 and 16 at low discharges were less than at comparable discharges in the other subwatersheds.

The relationships between the stream chemistry rating curves and subwatershed morphometric characteristics have not been verified for other watersheds. Extrapolation of these relationships to different geographic regions should be done with caution and verified with field monitoring.

CALIBRATION

The sediment and water chemistry rating curves describe the natural relationship between transport and concentration and stream discharge for the various water quality parameters. The construction of roads, harvesting and slash disposal will influence the stream discharge and the supply of sediment and dissolved ions. Shifts in the rating curves may be evident following management activities. It is hypothesized that changes in the rating curves indicate alterations of channel hydraulics or sediment and ion availability from upstream sources. Increases in the annual production of sediment or any specific ion, without a corresponding shift in the rating curve, indicate that increases in streamflow volumes are the primary cause of increased production.

Pre and post treatment rating curves can be statistically compared using analysis of covariance, which will indicate any changes in the slope or intercept coefficients of the rating curve regressions. A significant change in either of the coefficients should be attributed to management activities.

Hydrologic calibration equations, presently being developed by the Moscow Watershed Research Work Unit personnel of the USFS, can be used to predict stream discharge for pretreatment conditions. Pretreatment discharge used in conjunction with pretreatment rating curves can predict sediment or ion transport or concentration had the management activity not occurred. Actual post treatment stream discharge used in conjunction with pretreatment rating curves allow for quantification of the increases in concentration or transport due to changes in discharges following treatment. Any additional increase in concentration or transport can be attributed to changes in the channel hydraulics and/or to increases in sediment or ion supply rates due to treatment.

The use of predicted discharges with the rating curves may result in large standard deviations. The independent variable, discharge, has a variance associated with it since it also is a predicted value. This variance should be incorporated in the prediction of the sediment transport rates. The variance about the predicted discharge value can be incorporated in the same way that sampling error is associated with an independent variable. This method is discussed in Schumacher and Chapman (1948).

This methodology is not statistically perfect because of a lack of independence. Discharge in the "control" subwatershed is under the same climatological influences as the subwatersheds in which discharge is predicted. This does not affect the statistical comparison of pre and post treatment rating curves or the comparison of yields of sediment or ions. Partition of the changes in the rating curves as caused by either increases in discharge or increases in supply may come under criticism.

An additional caution must also be considered. The pretreatment rating curves do not reflect the relationships for the total range of natural variability due to climatological controls. With only three years of data it is possible that climatological conditions during post treatment years may be substantially different than during the period of pretreatment. Results must then be considered speculative in nature.

Appendix 1

Definitions of the Geomorphic Variables

Variable and Symbol	Definition and Where Used or Defined
Basin Area (A)	Total area of the basin within its topographic divide. Planimetred from USDA Forest Service maps (scale 8 inches = 1 mile). (Horton 1945).
Basin Perimeter	Total distance of perimeter following the topographic divide of the basin (Smith 1950).
Maximum Length (L_b)	Maximum straight line distance from mouth to the furthest point on the watershed divide (Horton 1945).
Maximum Width (B_r)	Maximum straight line distance between topographic divides, perpendicular to L_b (Horton 1945).
Lemniscate Ratio (L_r)	The ratio of the actual basin perimeter divided by the perimeter of its ideal lemniscate counterpart (Chorley et al., 1957).
Lemniscate Constant (k)	$\frac{(L_b)^2 \pi}{4A}$ (Chorley et al., 1957).
Basin Circularity (R_c)	The basin area, A, divided by the area of a circle having the same perimeter length, P (Miller 1954).
Basin Width Factor (R_w)	The diameter of a circle having the same basin area divided by basin width, B_r.
Basin Elongation (R_e)	The diameter of a circle having the same basin area divided by basin length, L_b (Schumm 1956).
Form Factor (R_f)	The basin area, A, divided by the square of the basin length, L_b (Horton 1945).
Shape Factor (R_s)	The basin length, L_b, divided by the basin width, L_w (Horton 1945).
Aspect (α)	The general aspect of the basin expressed as an azimuth.
Mean Elevation ($\bar{E}$)	The average of the highest and lowest elevation in the basin.

Total Basin Relief (H)	The difference between the highest and lowest elevation in the basin (Strahler 1952).
Relief Ratio (R_h)	The total basin relief, R, divided by the maximum length of the basin, L_b (Schumm 1956).
Ruggedness Number (R_n)	The drainage density, D, multiplied by the total basin relief, R, in miles (Doornkamp and King 1971).
Stream Lengths (L, L_1, L_2)	Measured from USDA Forest Service maps (scale 8 inches = 1 mile) (Horton 1945).
Mean Stream Lengths ($\overline{L}_1$, $\overline{L}_2$)	The stream length for a given order divided by the number of streams of that order (Horton 1945).
Number of Streams (N, N_1, N_2)	Based on perennial and intermittant streams shown on USDA Forest Service maps (scale 8 inches = 1 mile) (Horton 1945).
Stream Length Ratio (R_1)	The mean length of second order streams, $\overline{L}_2$, divided by the mean length of first order streams, $\overline{L}_1$ (Horton 1945).
Drainage Density (D)	The total stream length, L, divided by the basin area, A (Horton 1945).
Stream Frequency (F)	The total number of streams, N, divided by the basin area, A (Horton 1945).
Texture ratio (T)	The total number of streams, N, divided by the basin perimeter, P (Smith 1950).

Appendix 2

Geomorphic characteristics of the ten Horse Creek Subwatersheds

Geomorphic Characteristics of the ten Horse Creek Subwatersheds.

SUBWATERSHED NUMBER	AREA ACRES	PERIMETER MILES	MAXIMUM LENGTH MILES	MAXIMUM WIDTH MILES	LEMNISCATE RATIO	LEMNISCATE CONSTANT	BASIN CIRCULARITY	BASIN WIDTH FACTOR
2	143	2.271	0.992	0.280	1.1002	3.463	0.544	1.902
4	348	3.293	1.176	0.795	0.6360	1.997	0.630	1.047
6	256	3.018	1.280	0.455	1.0232	3.215	0.552	1.568
8	364	3.413	1.144	0.817	0.5755	1.807	0.613	1.041
9	58	1.400	0.610	0.218	1.0833	3.227	0.581	1.560
10	161	2.065	0.814	0.487	0.6592	2.067	0.741	1.162
12	207	2.391	0.901	0.473	0.6269	1.972	0.711	1.359
14	154	1.986	0.807	0.473	0.6768	2.123	0.766	1.172
16	70	1.667	0.671	0.225	1.1100	3.228	0.495	1.659
18	213	2.518	0.765	0.694	0.4399	1.381	0.659	0.938

SUBWATERSHED NUMBER	BASIN ELONGATION	FORM FACTOR	SHAPE FACTOR	ASPECT DEGREES	MEAN ELEVATION FEET	RELIEF MILES	RELIEF RATIO	RUGGEDNESS NUMBER
2	0.538	0.227	3.535	202	4960	0.303	0.306	1.026
4	0.708	0.393	1.480	178	4980	0.303	0.258	1.134
6	0.558	0.244	2.811	158	4950	0.269	0.210	1.240
8	0.744	0.434	1.401	147	5005	0.248	0.217	0.552
9	0.557	0.243	2.802	135	4790	0.155	0.255	0.793
10	0.695	0.379	1.672	146	4985	0.206	0.253	1.133
12	0.713	0.399	1.906	147	5190	0.223	0.248	0.969
14	0.686	0.369	1.708	147	5230	0.227	0.282	1.010
16	0.557	0.243	2.980	198	5438	0.181	0.270	0.735
18	0.851	0.568	1.103	175	5458	0.173	0.227	0.765

(continued).

SUBWATERSHED NUMBER	TOTAL STREAM LENGTH MILES	MEAN LENGTH OF 1ST ORDER STREAMS MILES	MEAN LENGTH OF 2ND ORDER STREAMS MILES	NUMBER OF 1ST ORDER STREAMS	NUMBER OF 2ND ORDER STREAMS
2	0.756	0.756	0.000	1	0
4	2.035	0.419	0.361	4	1
6	1.844	0.771	0.302	2	1
8	1.266	0.460	0.346	2	1
9	0.463	0.463	0.000	1	0
10	1.381	0.257	0.352	4	1
12	1.403	0.393	0.224	3	1
14	1.069	0.284	0.218	3	1
16	0.444	0.444	0.000	1	0
18	1.467	0.251	0.463	4	1

SUBWATERSHED NUMBER	NUMBER OF STREAMS	STREAM LENGTH RATIO	DRAINAGE DENSITY MILE^{-1}	STREAM FREQUENCY NO./MILE^{2}	TEXTURE RATIO NO./MILE
2	1	0.000	3.385	4.480	0.440
4	5	0.860	3.743	9.200	1.518
6	3	0.390	4.609	7.500	0.994
8	3	0.750	2.225	5.280	0.879
9	1	0.000	5.109	11.035	0.714
10	5	1.370	5.489	19.880	2.422
12	4	0.570	4.337	12.370	1.673
14	4	0.770	4.443	16.620	2.014
16	1	0.000	4.059	9.143	0.600
18	5	1.850	4.409	15.020	1.986

SUBWATERSHED NUMBER	ON-SITE SEDIMENT PRODUCTION HAZARD
2	596
4	484
6	538
8	403
9	483
10	667
12	733
14	617
16	346
18	229

Appendix 3

Acreages and percentages of land types
occurring in the ten Horse Creek Subwatersheds.

LAND TYPES
PERCENTAGES

SUBWATERSHED	21F	22	22F	24	24C	24F	30	31	32	51H	61C
2	0.0	0.0	0.0	35.80	0.0	0.0	0.0	30.35	26.72	0.0	7.13
4	0.0	11.32	0.0	20.83	20.95	0.0	0.0	9.17	29.89	0.0	7.84
6	0.0	0.0	0.0	54.73	10.35	0.0	0.0	0.0	22.85	0.0	12.07
8	0.0	0.0	0.0	73.68	0.0	0.0	0.0	0.0	22.14	0.0	4.18
9	0.0	0.0	0.0	91.82	0.0	0.0	0.0	0.0	0.0	0.0	8.18
10	0.0	0.0	0.0	53.60	0.0	0.0	19.44	0.0	12.80	0.0	14.16
12	0.0	0.0	0.0	0.0	0.0	0.0	80.87	0.0	19.13	0.0	0.0
14	0.0	0.0	0.0	31.88	0.0	0.0	56.17	0.0	11.95	0.0	0.0
16	0.0	0.0	0.0	75.76	0.0	9.49	0.0	0.0	14.75	0.0	0.0
18	28.73	0.0	20.94	25.96	0.0	0.0	0.0	0.0	19.46	4.93	0.0

LAND TYPES
(ACRES)

SUBWATERSHED	21F	22	22F	24	24C	24F	30	31	32	51H	61C
2	0.0	0.0	0.0	51.2	0.0	0.0	0.0	43.4	38.2	0.0	10.2
4	0.0	39.4	0.0	72.5	72.9	0.0	0.0	31.9	104.0	0.0	27.3
6	0.0	0.0	0.0	140.1	26.5	0.0	0.0	0.0	58.5	0.0	30.9
8	0.0	0.0	0.0	268.2	0.0	0.0	0.0	0.0	80.6	0.0	15.2
9	0.0	0.0	0.0	53.3	0.0	0.0	0.0	0.0	0.0	0.0	4.7
10	0.0	0.0	0.0	86.3	0.0	0.0	31.3	0.0	20.6	0.0	22.8
12	0.0	0.0	0.0	0.0	0.0	0.0	167.4	0.0	39.6	0.0	0.0
14	0.0	0.0	0.0	49.1	0.0	0.0	86.5	0.0	18.4	0.0	0.0
16	0.0	0.0	0.0	53.0	0.0	6.6	0.0	0.0	10.3	0.0	0.0
18	61.2	0.0	44.6	55.3	0.0	0.0	0.0	0.0	41.4	10.5	0.0

SECONDARY PROCESSES
ACRES

SUBWATERSHED	WEAK FLUVIAL ACTION	MODERATE FROST CHURNED	SOLIFLUCTION
2	10.2	0.0	0.0
4	100.0	0.0	0.0
6	57.4	0.0	0.0
8	15.2	0.0	0.0
9	4.7	0.0	0.0
10	22.8	0.0	0.0
12	0.0	0.0	0.0
14	0.0	0.0	0.0
16	0.0	6.6	0.0
18	0.0	105.8	10.5

SECONDARY PROCESSES
PERCENTAGES

SUBWATERSHED	WEAK FLUVIAL ACTION	MODERATE FROST CHURNED	SOLIFLUCTION
2	7.13	0.0	0.0
4	28.79	0.0	0.0
6	22.42	0.0	0.0
8	4.18	0.0	0.0
9	8.18	0.0	0.0
10	14.16	0.0	0.0
12	0.0	0.0	0.0
14	0.0	0.0	0.0
16	0.0	9.49	0.0
18	0.0	49.67	4.93

LAND TYPE ASSOCIATIONS (ACRES)

SUBWATERSHED	FLUVIAL	COLLUVIAL DRIFT AND FROST CHURNED	MASS WASTED	BREAKS
2	51.2	81.6	0.0	10.2
4	184.8	135.9	0.0	27.3
6	166.6	58.5	0.0	30.9
8	268.2	80.6	0.0	15.2
9	53.3	0.0	0.0	4.7
10	86.3	51.0	0.0	22.8
12	0.0	207.0	0.0	0.0
14	49.1	104.9	0.0	0.0
16	59.6	10.3	0.0	0.0
18	161.1	41.4	0.0	0.0

LAND TYPE ASSOCIATIONS PERCENTAGES

SUBWATERSHED	FLUVIAL	COLLUVIAL DRIFT AND FROST CHURNED	MASS WASTED	BREAKS
2	35.80	57.06	0.0	7.13
4	53.10	39.05	0.0	7.84
6	65.08	22.85	0.0	12.07
8	73.68	22.14	0.0	4.18
9	91.82	0.0	0.0	8.18
10	53.60	32.24	0.0	14.16
12	0.0	100.0	0.0	0.0
14	31.88	68.12	0.0	0.0
16	85.25	14.75	0.0	0.0
18	75.63	19.44	4.93	0.0

Appendix 4

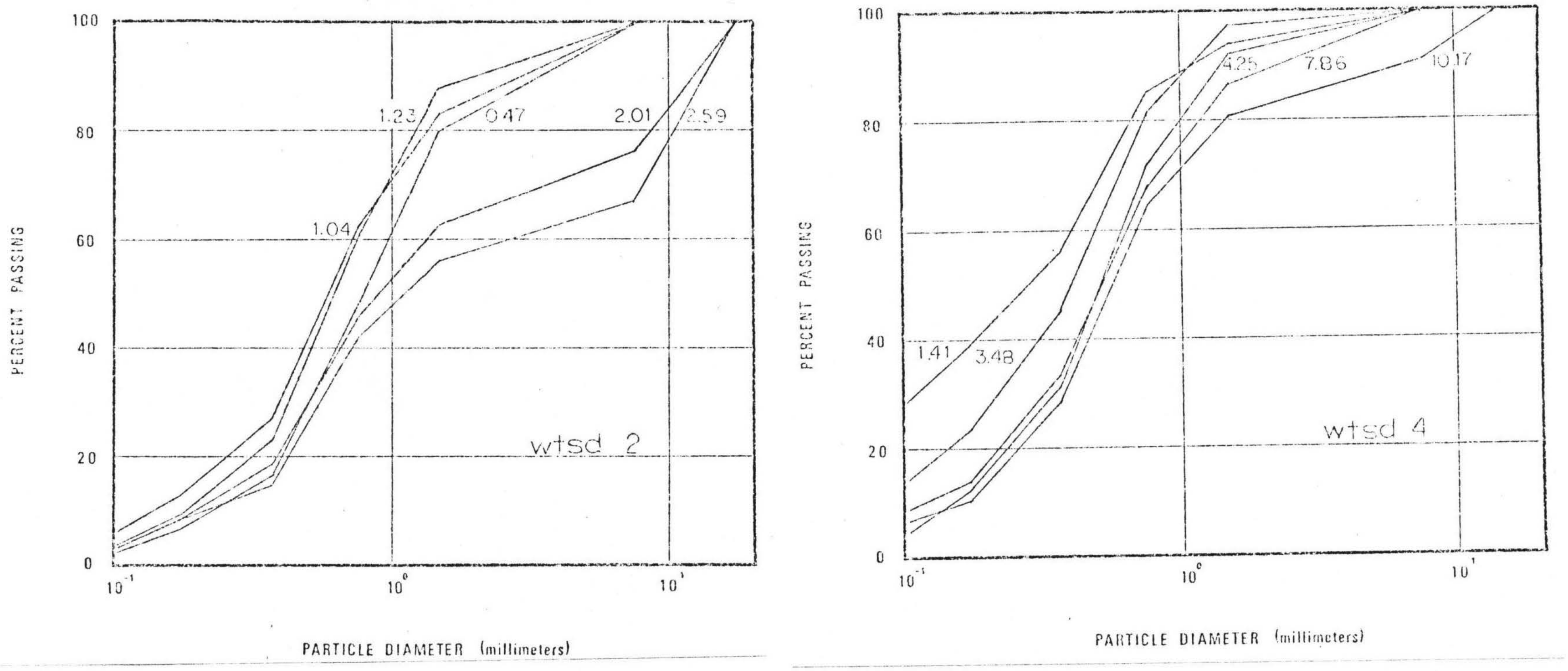
Correlation matrix for the twenty geomorphic variables used to describe the Horse Creek Subwatersheds

	L_b	Br	P	K	R_c	R_h	R_n	R	T	F
L_b	1.00									
Br	0.55	1.00								
P	0.90	0.84	1.00							
K	-0.06	-0.82	-0.42	1.00						
R_c	-0.12	0.37	0.01	-0.72	1.00					
R_h	-0.38	-0.53	-0.53	0.39	-0.01	1.00				
R_n	0.39	-0.09	0.10	0.19	0.22	0.16	1.00			
R	0.85	0.33	0.67	0.11	-0.11	0.17	0.50	1.00		
T	-0.12	0.43	0.05	-0.75	0.90	-0.15	0.32	-0.18	1.00	
F	-0.52	0.02	-0.41	-0.49	0.79	0.02	0.21	-0.53	0.88	1.00
D	-0.49	-0.45	-0.61	0.11	0.32	0.03	0.48	-0.51	0.47	0.73
R_1	0.02	0.69	0.32	-0.87	0.64	-0.40	0.03	-0.16	0.83	0.63
N_1	0.14	0.69	0.36	-0.84	0.75	-0.26	0.33	0.05	0.91	0.66
N_2	0.48	0.79	0.64	-0.79	0.69	-0.57	0.27	0.21	0.74	0.39
$\overline{L}_1$	0.54	-0.33	0.22	0.75	-0.71	0.05	0.27	0.57	-0.76	-0.80
L_1	0.79	0.63	0.77	-0.36	0.24	-0.43	0.63	0.62	0.37	-0.21
L_2	0.43	0.88	0.68	-0.83	0.52	-0.65	0.13	0.13	0.69	0.35
$\overline{E}$	-0.36	0.07	-0.14	-0.36	0.10	0.02	-0.32	-0.37	0.27	0.29
α	0.07	-0.16	0.04	0.32	-0.58	0.45	0.02	0.34	-0.40	-0.43
S	0.14	-0.25	-0.12	0.14	0.46	0.33	0.61	0.33	0.24	0.21

	D	R_1	N_1	N_2	$\overline{L}_1$	L_1	L_2	$\overline{E}$	α	S
D	1.00									
R_1	0.16	1.00								
N_1	0.25	0.89	1.00							
N_2	-0.00	0.74	0.82	1.00						
$\overline{L}_1$	-0.30	-0.68	-0.66	-0.39	1.00					
L_1	-0.04	0.38	0.62	0.74	0.13	1.00				
L_2	-0.04	0.89	0.85	0.91	-0.42	0.69	1.00			
$\overline{E}$	-0.03	0.35	0.23	0.11	-0.46	-0.18	0.16	1.00		
α	-0.33	-0.20	-0.22	-0.44	0.35	-0.07	-0.27	0.39	1.00	
S	0.29	-0.22	0.08	0.15	0.12	0.21	-0.17	-0.44	-0.36	1.00

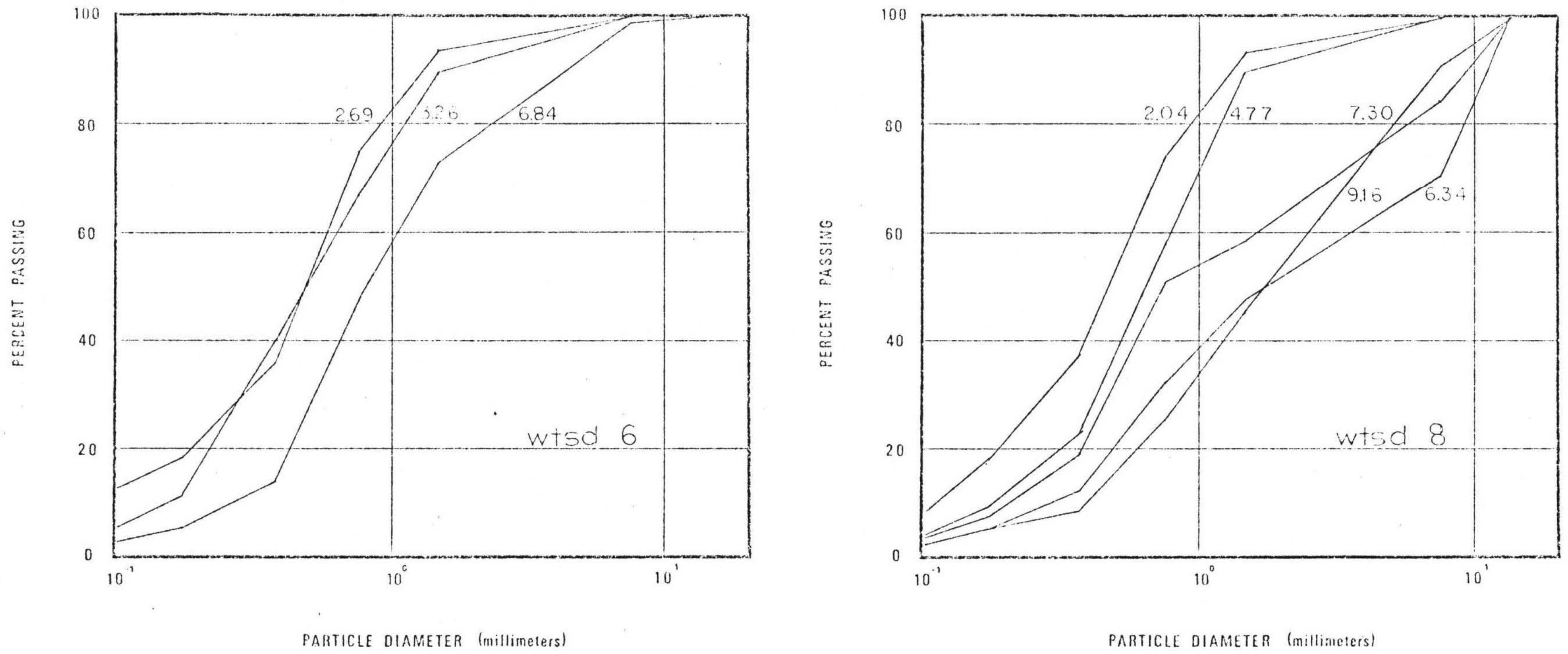
Appendix 5

Particle size distribution curves for the bedload samples collected in water year 1976



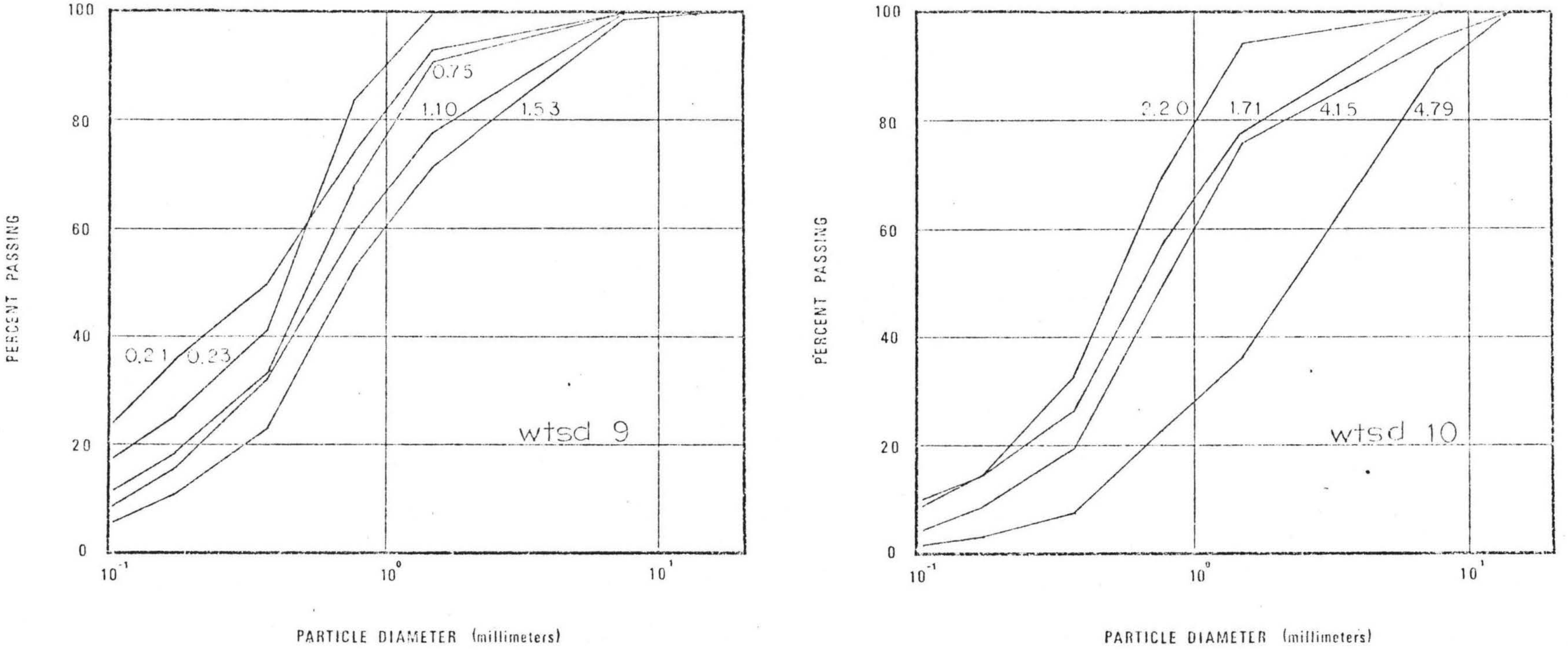
Particle size distribution of bedload samples collected during water year 1976 on the Horse Creek Subwatersheds 2 and 4.

Note: The number adjacent to each curve denotes the stream discharge in cubic feet per second at the time of sampling.



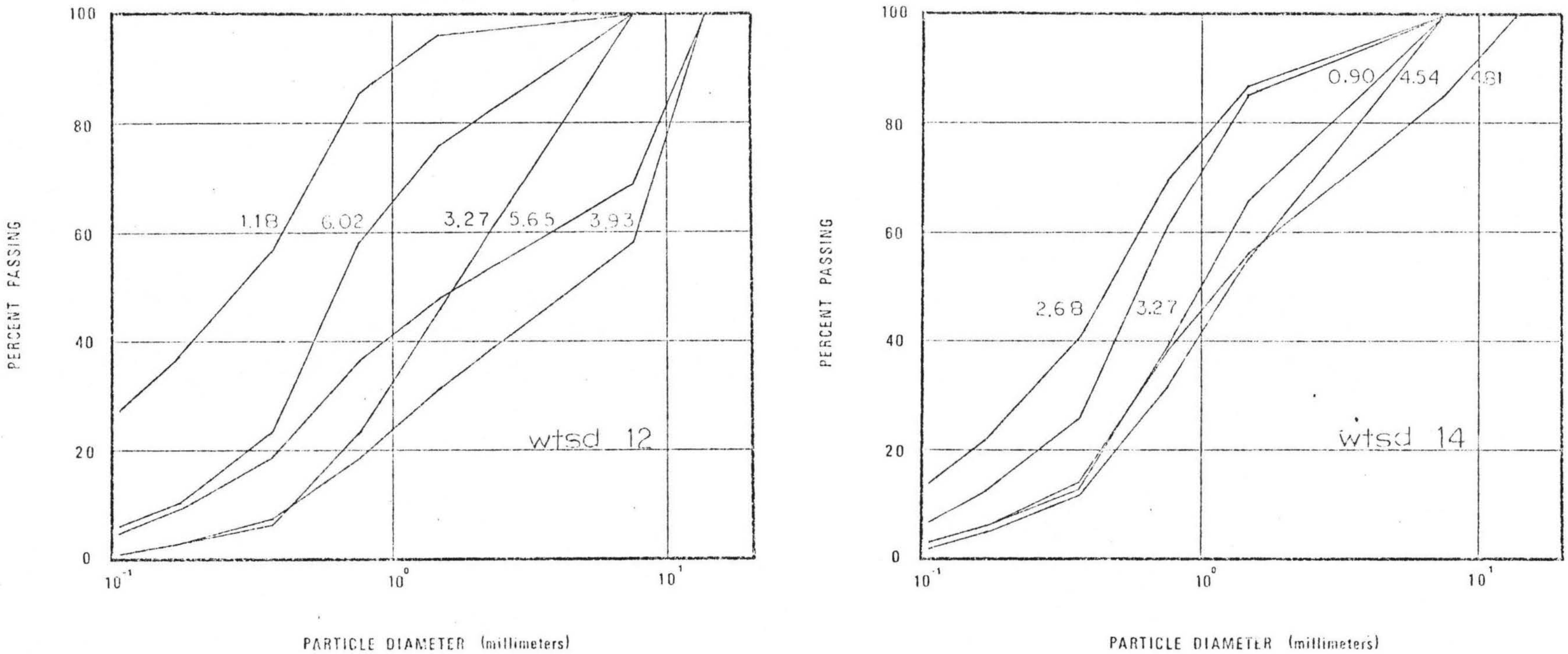
Particle size distribution of bedload samples collected during water year 1976 on the Horse Creek Subwatersheds 6 and 8.

Note: The number adjacent to each curve denotes the stream discharge in cubic feet per second at the time of sampling.



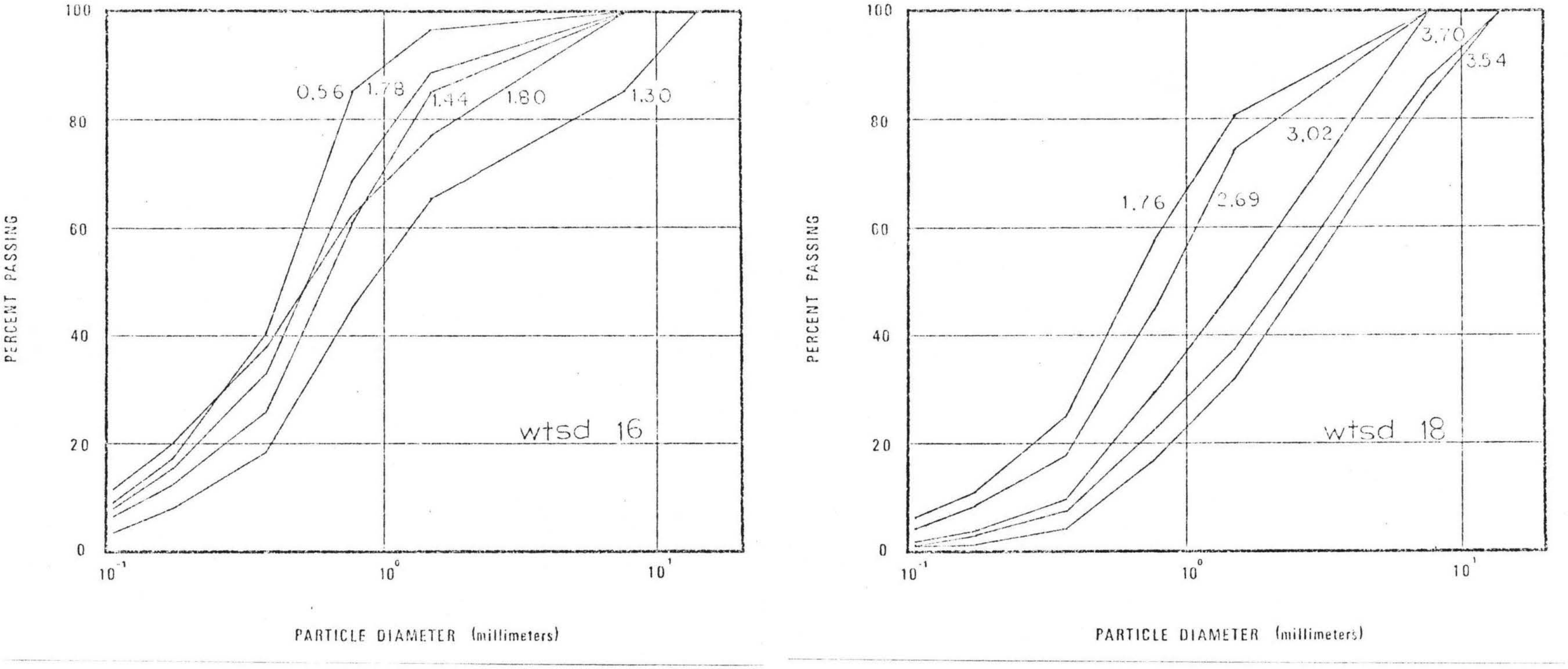
Particle size distribution of bedload samples collected during water year 1976 on the Horse Creek Subwatersheds 9 and 10.

Note: The number adjacent to each curve denotes the stream discharge in cubic feet per second at the time of sampling.



Particle size distribution of bedload samples collected during water year 1976 on the Horse Creek Subwatersheds 12 and 14.

Note: The number adjacent to each curve denotes the stream discharge in cubic feet per second at the time of sampling.

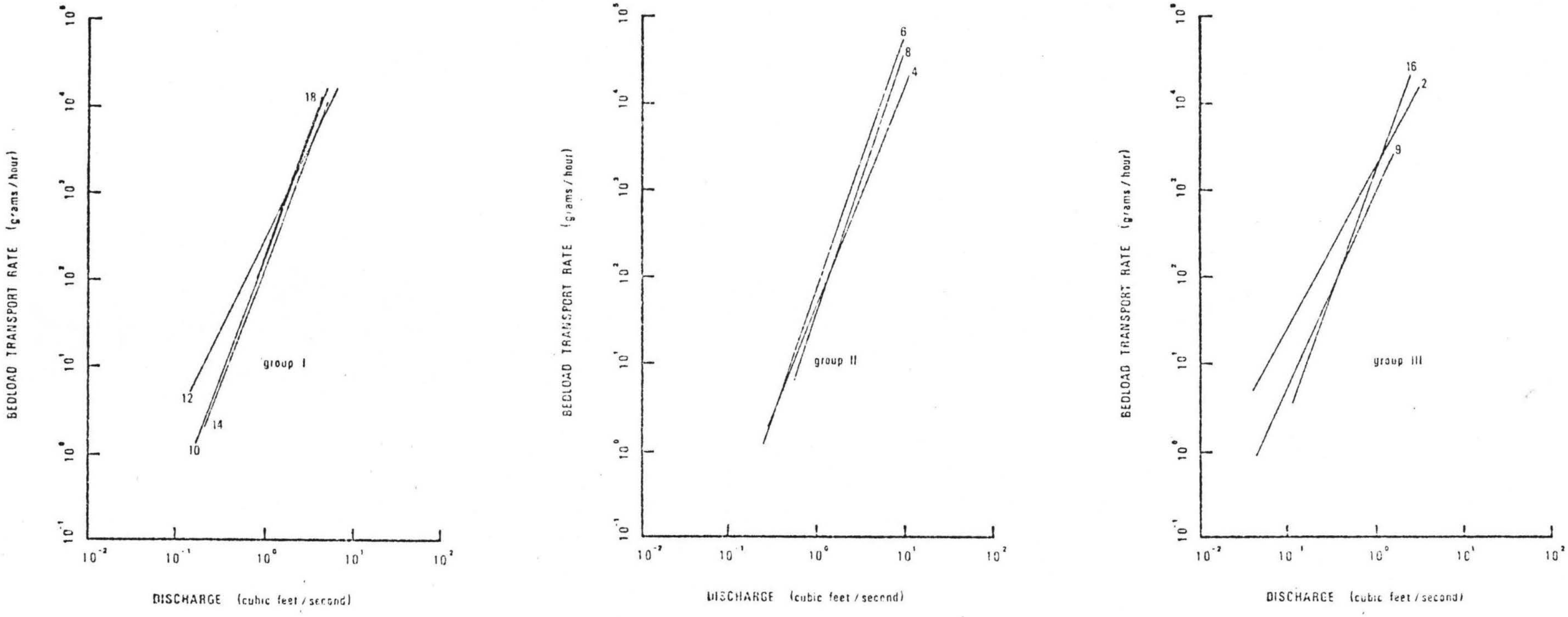


Particle size distribution of bedload samples collected during water year 1976 on the Horse Creek Subwatersheds 16 and 18.

Note: The number adjacent to each curve denotes the stream discharge in cubic feet per second at the time of sampling.

Appendix 6

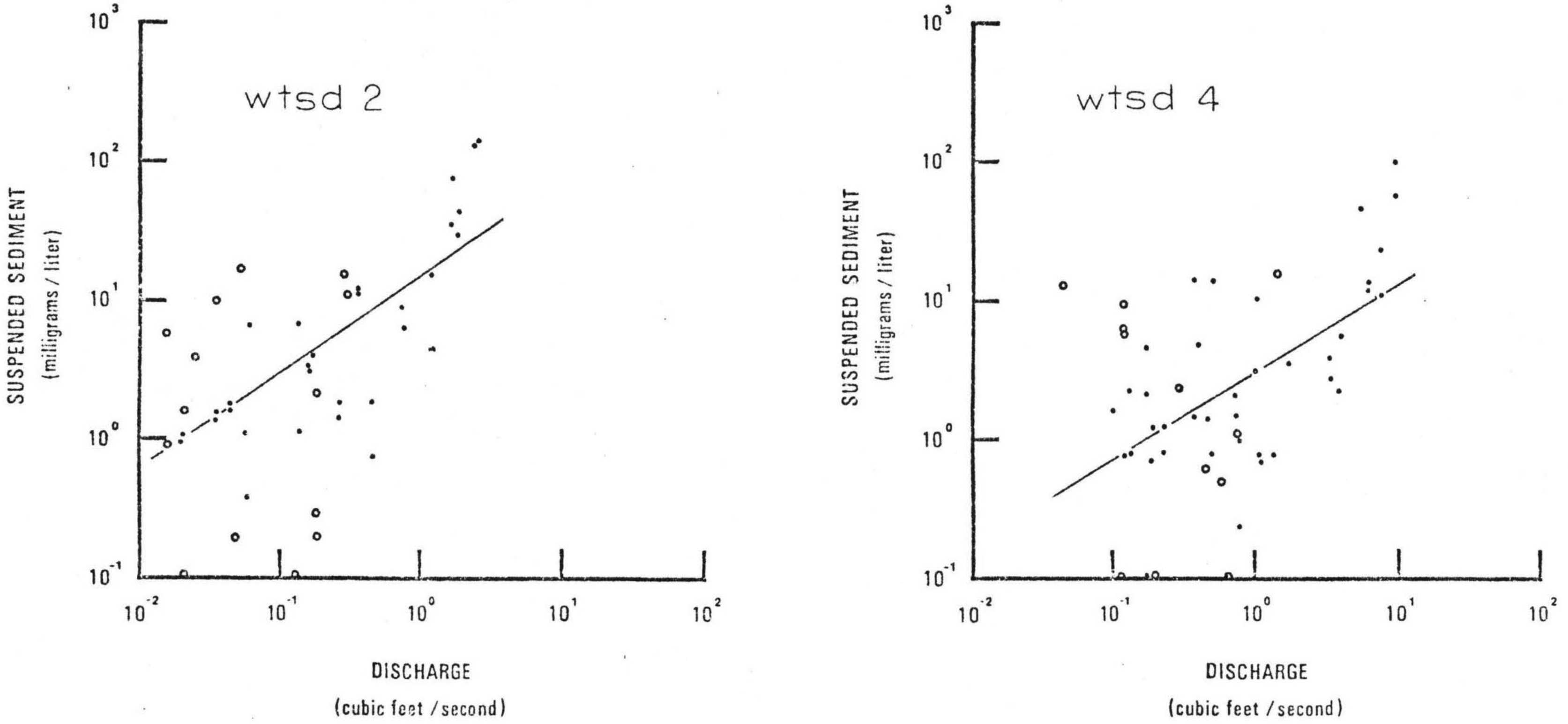
Bedload rating curves for the individual Horse Creek Subwatersheds and for the geomorphic groupings of subwatersheds



Bedload rating curves for the individual Horse Creek Subwatersheds and for the geomorphic groupings of subwatersheds.

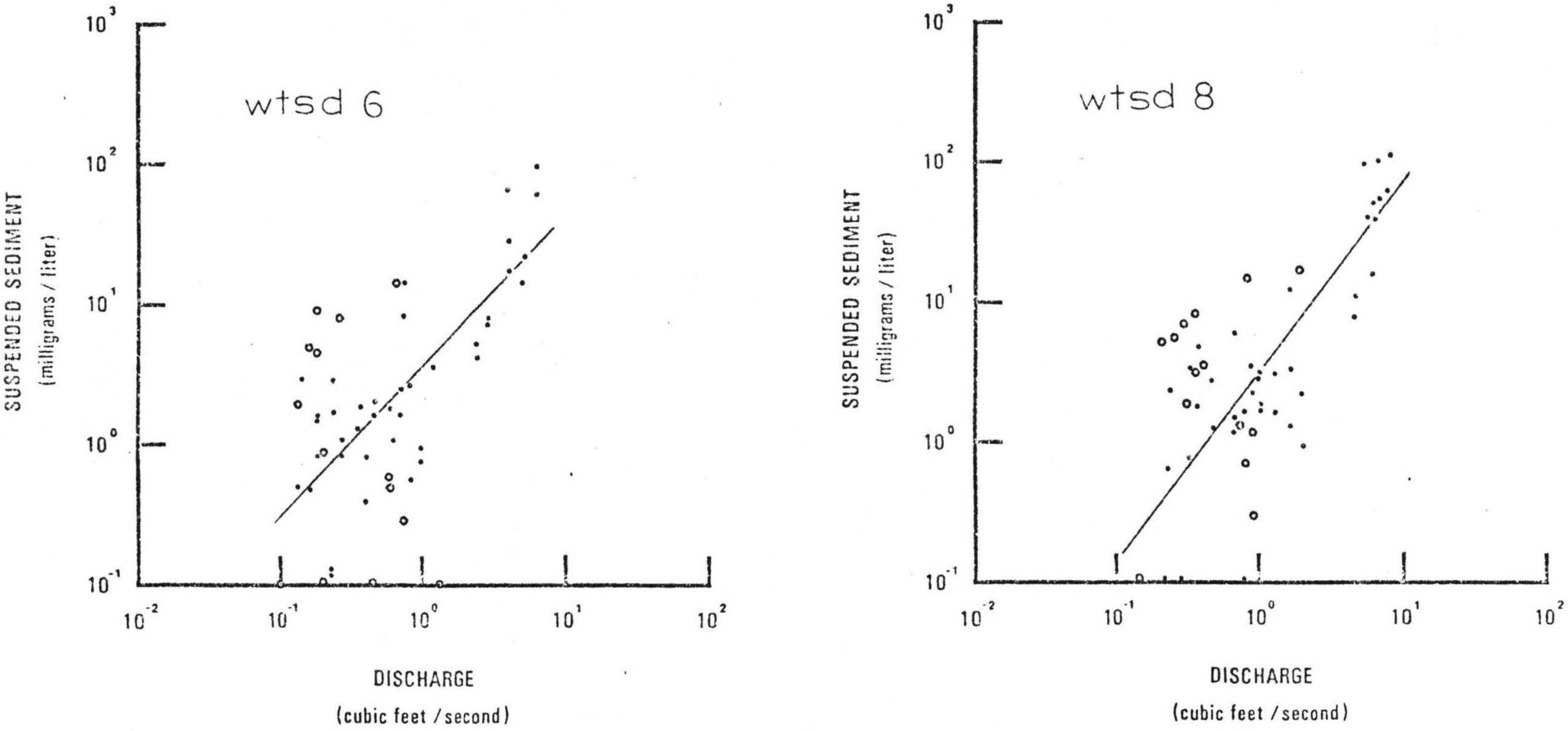
Appendix 7

Suspended sediment rating curves and data points for water years 1975, 1976, and 1977



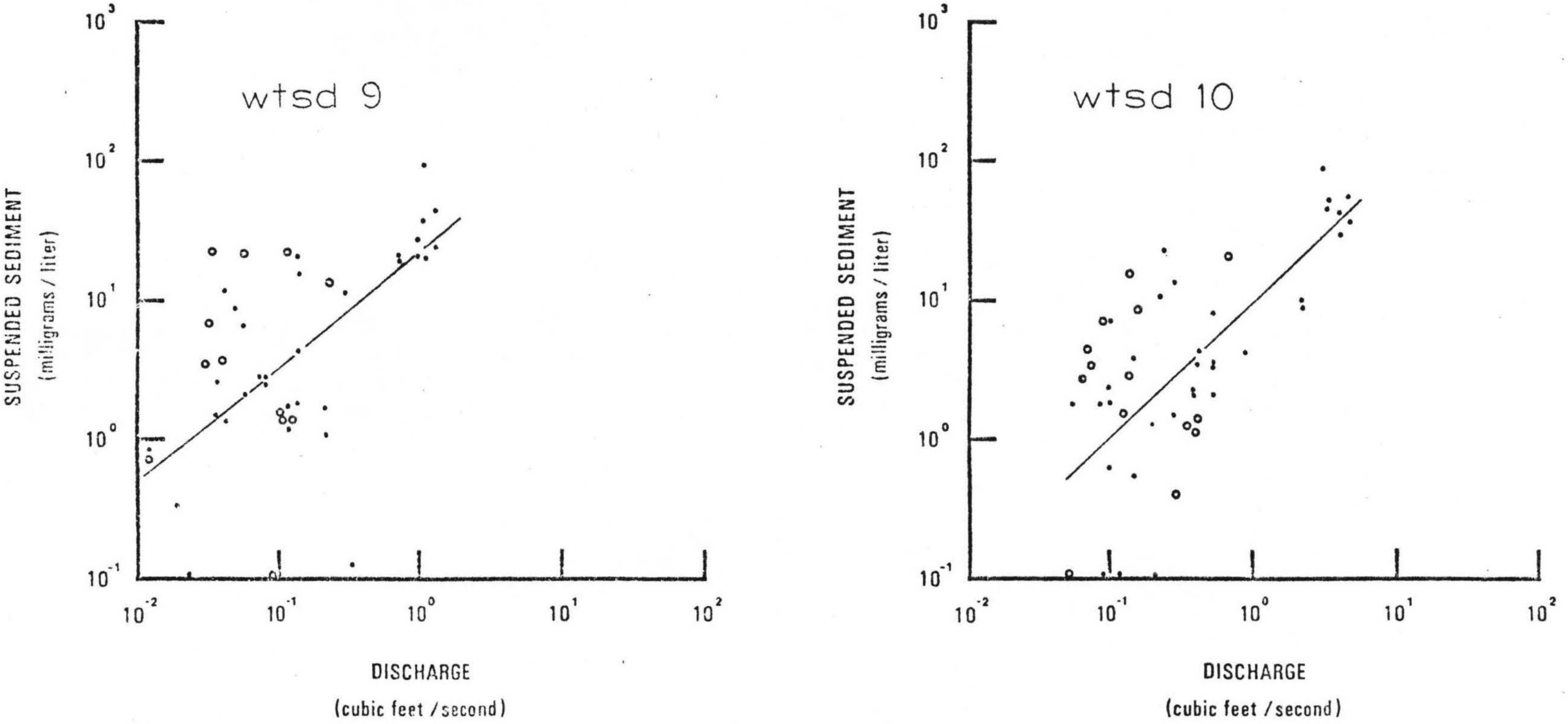
Suspended sediment rating curves and data points for water years 1975, 1976, and 1977.

Note: Solid dots are 1975 and 1976 data. Open dots are 1977 data.



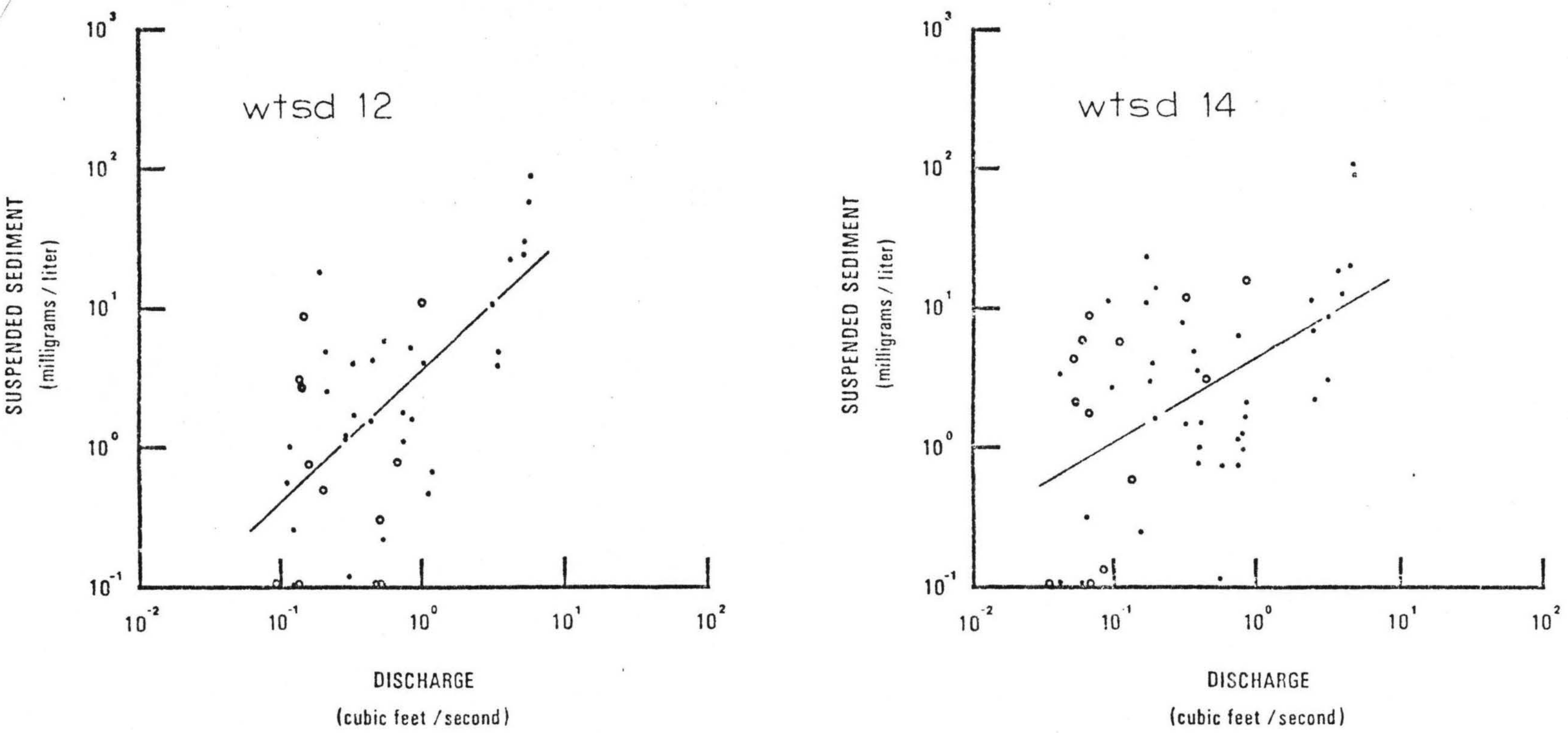
Suspended sediment rating curves and data points for water years 1975, 1976, and 1977.

Note: Solid dots are 1975 and 1976 data. Open dots are 1977 data.



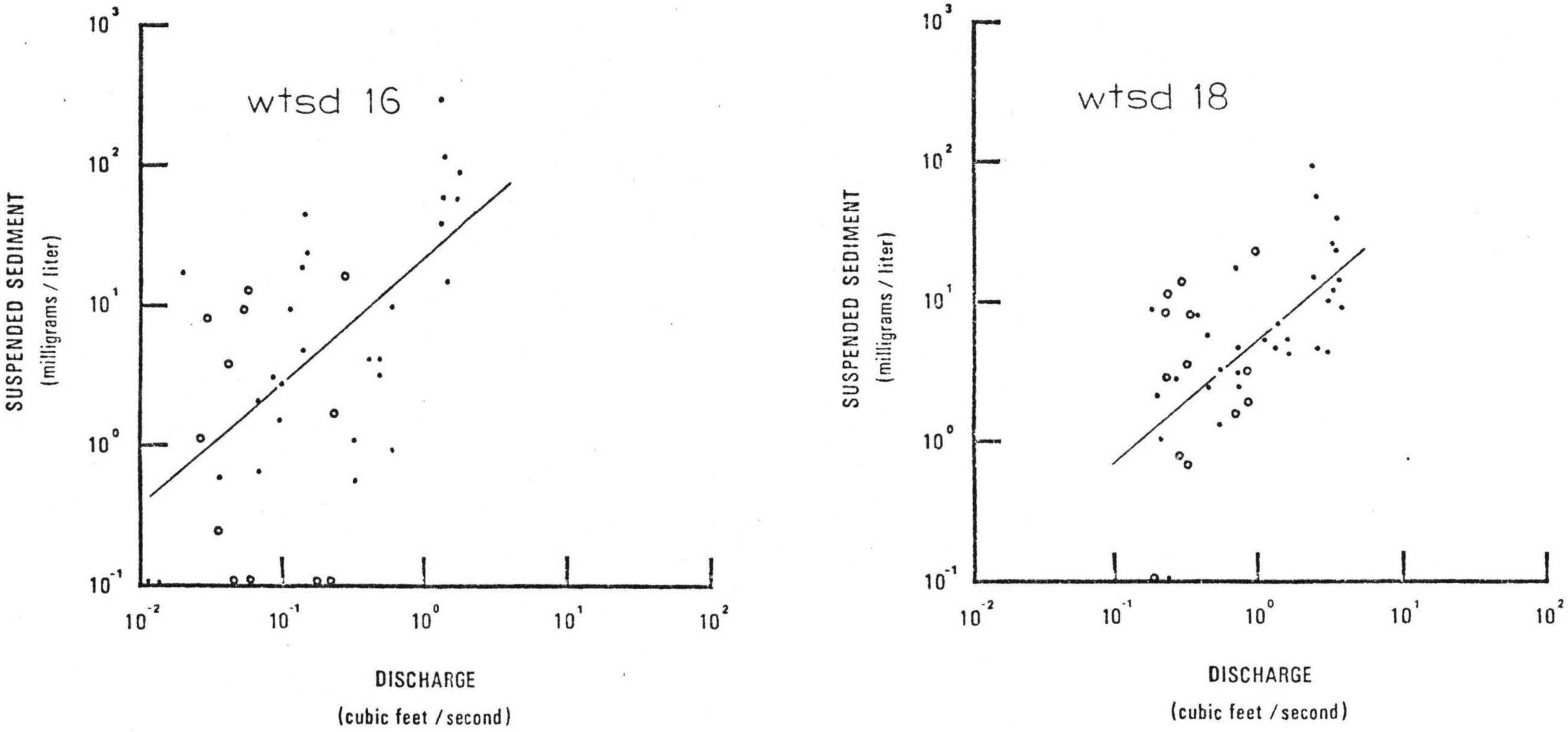
Suspended sediment rating curves and data points for water years 1975, 1976, and 1977.

Note: Solid dots are 1975 and 1976 data. Open dots are 1977 data.



Suspended sediment rating curves and data points for water years 1975, 1976, and 1977.

Note: Solid dots are 1975 and 1976 data. Open dots are 1977 data.



Suspended sediment rating curves and data points for water years 1975, 1976, and 1977.

Note: Solid dots are 1975 and 1976 data. Open dots are 1977 data.

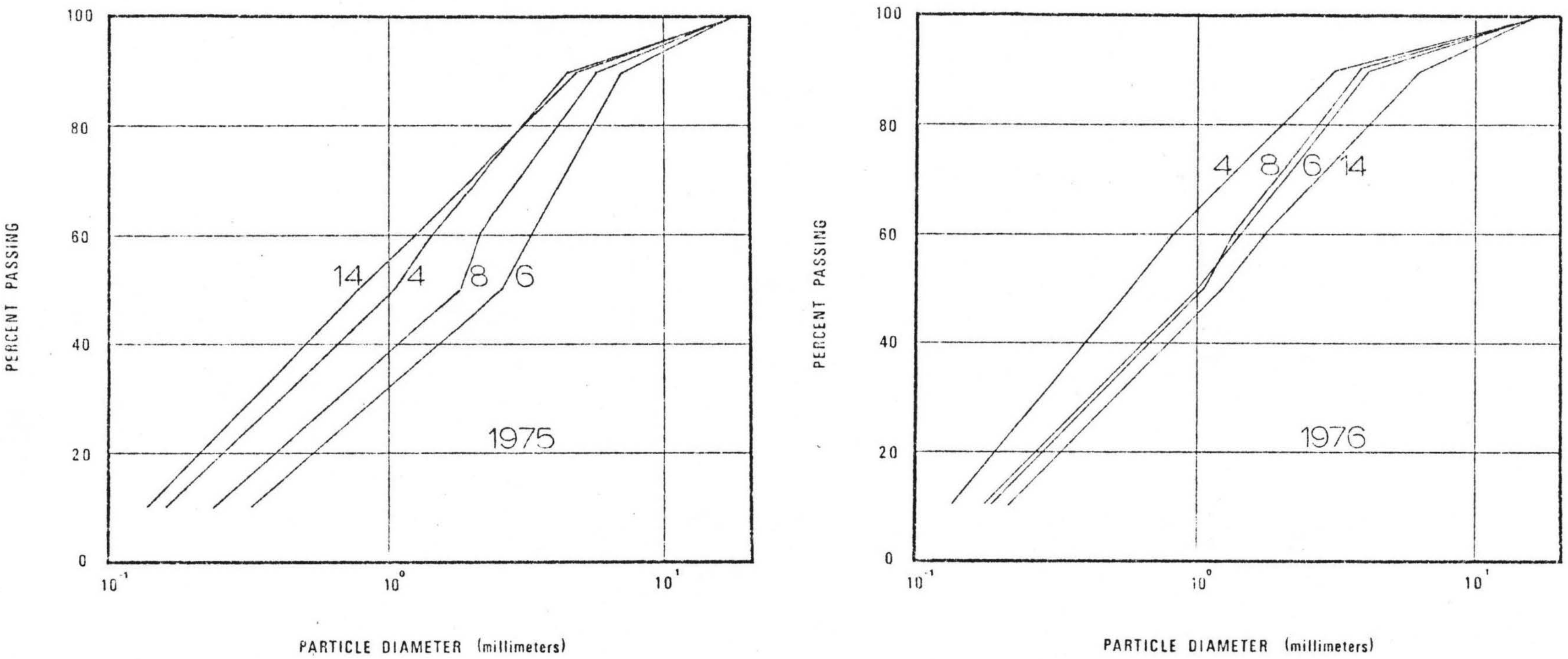
Regression coefficients and statistical information for the suspended sediment rating curves for the Horse Creek Subwatersheds for water years 1975, 1976, and 1977.

Subwatershed	β_0	β_1	Standard Deviation	R^2	Significance
2	1.1230	0.6575	0.68	0.35	** [1]
4	0.4247	0.5273	0.65	0.20	**
6	0.5391	0.9651	0.55	0.46	**
8	0.5316	1.0578	0.54	0.49	**
9	1.2344	0.6699	0.58	0.33	**
10	0.9547	0.8330	0.54	0.45	**
12	0.4482	0.7757	0.64	0.32	**
14	0.6355	0.5939	0.62	0.28	**
16	1.1982	0.8436	0.69	0.45	**
18	0.7234	0.8000	0.51	0.32	**

1/ ** indicates significance at $\alpha = 0.01$.

Appendix 8

Particle size distribution curves for the sediment deposited in the debris basins for water years 1975 and 1976



Particle size distribution curves for the sediment deposited in the debris basins for water years 1975 and 1976.

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Idaho Water Resources Research Institute
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Principal component analysis was performed on a set of geomorphic descriptors for ten undisturbed forested watersheds in north central Idaho. This analysis provided a means of watershed classification and was an aid in the selection of geomorphic variables useful in explaining differences in sedimentation processes between watersheds and/or groups of watersheds. Total basin area and relief ratio were the two most useful descriptors in evaluating sedimentation differences.

Total annual sediment yields exhibit a great deal of annual variability largely due to annual differences in water yields, influenced by snowmelt volumes and snowmelt rates. Approximately 95% of the annual sediment production occurs during the snowmelt season. For these watersheds, having soils with relatively high proportions of silts and clays, sediment transported in suspension is the dominant process, accounting for 49-74% of the sediment productions.

The results of this study indicate that geomorphology is related to water chemistry and sedimentation processes and there is a potential for better areal extrapolation of research results by incorporation of certain geomorphologic parameters.

Idaho, Geomorphology, sediment yield, watershed management, runoff, forestry, water chemistry

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