SEDIMENT YIELDS IN EASTERN MONTANA

Summary of data and proposed

techniques for estimating sediment

yields from small, ungaged watersheds

by John H. Lambing

U.S. Geological Survey

Water-Resources Investigations Report 84-4200

Prepared in cooperation with the

U.S. BUREAU OF LAND MANAGEMENT

Helena, Montana
November 1984

UNITED STATES DEPARTMENT OF THE INTERIOR

WILLIAM P. CLARK, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

District Chief
U.S. Geological Survey
428 Federal Building
301 South Park
Drawer 10076
Helena, MT 59626-0076

Copies of this report can be purchased from:

Open-File Services Section
Western Distribution Branch
U.S. Geological Survey
Box 25425, Federal Center
Denver, CO 80225-0425

CONTENTS

Page

Abstract 1
Introduction 1
Purpose and scope 2
Description of study area 2
Climate 2
Topography and drainage 4
Methods for determining sediment yields 4
Reservoir sedimentation surveys 5
Suspended-sediment sampling in streams 5
Indirect estimation 6
Summary of sediment-yield data 7
Estimating sediment yields from small, ungaged watersheds 8
Approach concepts 8
Basin characteristics 9
Sediment yield 10
Drainage area 10
Drainage density 10
Relief-length ratio 10
Width-length ratio 11
Meander ratio 11
Forest cover 11
Mean annual precipitation 11
Streamflow magnitudes 11
Multiple-regression analysis 12
Evaluation of regression equations 14
Limitations in the application of regression equations 15
Data segregation 16
Geology 16
Soils 17
Vegetation/soil complexes 18
Results and interpretation 18
Summary 24
References cited 26
Supplemental data 29

ILLUSTRATIONS

Figure 1-3. Maps showing:
1. Location of study area and sites where sediment yields have been determined 3
2. Geographical factors (G_f) for streamflow equations 13
3. Geographic distribution of vegetation/soil complexes A, B, and C 19
4. Graphs showing relationship of measured mean annual sediment yields to predicted mean annual sediment yields for vegetation/soil complexes A, B, and C 23

TABLES

Page

Table 1. Equations for estimating mean annual sediment yields from small, ungaged watersheds in eastern Montana 20
2-4. Matrix of simple correlation coefficients between basin characteristics for reservoirs in:
2. Vegetation/soil complex A 20
3. Vegetation/soil complex B 21
4. Vegetation/soil complex C 21
5. Summary of reservoir sedimentation surveys. 30
6. Summary of suspended-sediment yields at stream-sampling sites . . . 38
7. Summary of sediment yields determined by indirect estimation. . . . 40
8. Basin characteristics of reservoirs with drainage areas less than 2 square miles 42
9. Description of vegetation/soil complexes in eastern Montana 44

CONVERSION FACTORS

The following factors may be used to convert inch-pound units published herein to the International System of units (SI).

Multiply inch-pound unit	By	To obtain metric unit
acre-foot (acre-ft)	1,233	cubic meter
acre-foot per square mile (acre-ft/mi^2)	476.1	cubic meter per square kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second per square mile [(ft^3/s)/mi^2]	0.01093	cubic meter per second per square kilometer
foot (ft)	0.3048	meter (m)
inch (in.)	25.40	millimeter
mile (mi)	1.609	kilometer (km)
pound per cubic foot (lb/ft^3)	16.02	kilogram per cubic meter
square mile (mi^2)	2.590	square kilometer
ton (short)	907.2	kilogram

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) by the equation:

$$°C = 5/9\ (°F - 32)$$

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. NGVD of 1929 is referred to as sea level in this report.

SEDIMENT YIELDS IN EASTERN MONTANA

Summary of data and proposed techniques for estimating

sediment yields from small, ungaged watersheds

---

by John H. Lambing

ABSTRACT

Sediment-yield data for 121 sites in eastern Montana were compiled from previous local and regional studies for the purpose of establishing a regional data base. Methods used in the previous studies for determination of mean annual sediment yields include reservoir sedimentation surveys, stream sampling of suspended sediment at streamflow-gaging stations, and indirect estimation based on physical characteristics of the basin. The data summarized in this report can serve to illustrate regional variation of sediment yields or to identify areas where additional studies might be warranted.

Multiple-regression equations were developed and evaluated for their adequacy in estimating mean annual sediment yields from small, ungaged watersheds in eastern Montana. Sediment yields determined from reservoir surveys were used in regression analysis as the dependent variable, because they were considered to be the most representative of long-term yields. Independent variables consisted of basin characteristics that could be readily measured from maps or obtained from published sources. Consequently, the equations developed in this study can be used without onsite data.

Evaluation of equations indicated that the best prediction capability was obtained when reservoirs were segregated by the vegetation/soil complex of the basin. The predictive capability of regression equations developed for each of three classes of vegetation/soil complex, as indicated by the coefficient of determination (R^2), ranged from 0.59 to 0.96. Corresponding standard errors ranged from 95 to 20 percent. The equations are applicable for small drainage basins of 2 square miles or less within the study area and possibly in adjacent areas having similar physiographic and hydrologic characteristics. Considering the inherent variability of sediment yields, the equations may be better-suited to providing comparisons of relative magnitudes between basins rather than absolute values.

INTRODUCTION

Much of eastern Montana consists of sparsely vegetated, semiarid rangeland, which is subject to extremely variable and sometimes severe soil erosion. In addition, soil disturbances associated with various land-use practices may accelerate natural erosion rates and sediment delivery from affected watersheds. Numerous studies of sediment yield in selected basins of eastern Montana have been conducted by various Federal, State, and private agencies. These studies provide data for watersheds that vary substantially in size and are distributed over a large geographic area. Summarization of the data from previous investigations would permit effective illustration of areal variation in sediment yields and enable identification of areas where additional studies might be warranted.

A concern of land-management agencies is to minimize soil losses from watersheds and to prevent sedimentation problems in streams and reservoirs. Therefore, policy decisions regarding land use commonly take into account the impacts of various management options on sediment yields. To accurately assess such impacts, a means to predict potential sediment losses from specific sites is essential. Using existing data to define relationships between mean annual sediment yield and selected basin characteristics enables the development of equations to estimate sediment yield from small watersheds where onsite data on erosion rates and runoff are lacking. Such equations would be a useful management tool for agencies responsible for implementing soil conservation measures.

Purpose and scope

The purpose of this report is to (1) summarize existing sediment-yield data and (2) describe proposed techniques for estimating mean annual sediment yields from small, ungaged watersheds in eastern Montana. An extensive literature search was made in compiling available sediment-yield data. Because sediment yield is a function of many physical, climatic, and hydrologic factors, multiple-regression analysis was used to identify which basin characteristics exhibited statistically strong correlations to sediment yield. Equations were developed and evaluated for their adequacy in estimating mean annual sediment yields. To alleviate the need for collection of onsite data, basin characteristics were selected that could be measured from maps or other published sources. This report was prepared in cooperation with the U.S. Bureau of Land Management.

Description of study area

The area described in this report (fig. 1) extends, in general, from the Wyoming border north to the Missouri River, and from the Musselshell River east to the North and South Dakota borders. The area encompasses about 33,500 square miles. Most of the area is within the Fort Union and Powder River coal regions, where extensive development of coal resources is in progress in southeastern Montana and is expected to increase in areas of east-central Montana. Currently, the principal land use within the study area is livestock grazing. Dryland crops are produced in some upland areas, whereas irrigation farming generally occurs along the major streams and their larger tributaries.

Climate

The climate of eastern Montana is semiarid continental and is characterized by cold dry winters, cool moist springs, and warm dry summers and autumns. Large ranges in daily and annual temperatures are typical of the area. January is the coldest month, with average temperatures ranging from about 10°F in the northern parts of the study area to about 20°F in the southern parts. July is the warmest month, averaging about 70° to 72°F throughout the region (U.S. Department of Commerce, issued annually).

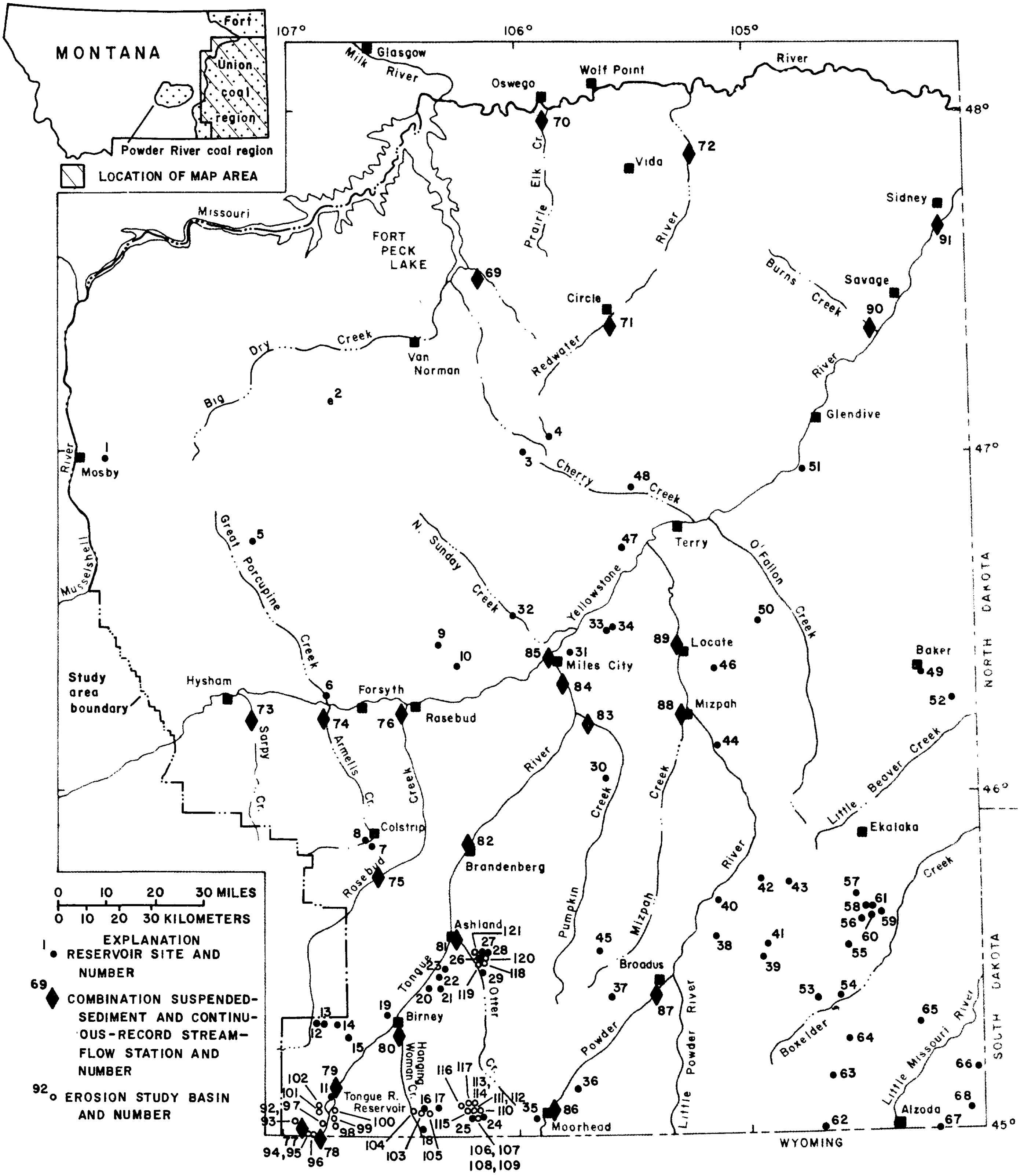


Figure 1.--Location of study area and sites where sediment yields have been determined.

Mean annual precipitation in the area ranges from 12 to 16 inches (U.S. Department of Commerce, issued annually). Most of the precipitation occurs as rainfall during late spring and early summer. June is commonly the wettest month, with precipitation averaging 3 to 5 inches. Unstable air masses, common during the summer, can create intense localized rainstorms of short duration. Such storms can result in rapid runoff, creating high peak flows that generally transport large sediment loads. Winter storms are typically of greater areal extent and, because of frozen precipitation and soil moisture, high flows are less common than during other times of the year. Winter snowfalls seldom accumulate to great depths as a result of winds and frequent thaws.

Topography and drainage

Because of the large areal extent of the study area, detailed descriptions of topographic features and drainages are difficult. However, some broad characterizations can be presented in relation to regional features. The study area is within the Great Plains physiographic province, which is further divided into the Glaciated Plains and Unglaciated Plains sections (Montagne and others, 1982). The southern edge of glaciation extends into the study area, just south of the Missouri River, and is typified by gently rolling hills with deeply incised channels in the downstream reaches of Missouri River tributaries. The rest of the study area south of the Missouri River is in the Unglaciated Plains section, which consists of a variety of landforms that can be separated into five general categories: (1) Isolated high hills in uplift areas, (2) easily erodable areas of extensive gullying and badland terrain; (3) gently rolling hills; (4) broad, flat upland benches and terraces; and (5) generally flat alluvial valleys.

Elevations in the plains range from about 2,000 feet above sea level where the Missouri River flows into North Dakota to about 4,000 feet in the southwestern part of the study area. Elevations of isolated hills exceed 4,500 feet. The relief south of the Yellowstone River is generally greater than that north of the Yellowstone, and the terrain is somewhat more rugged.

The two principal drainages in eastern Montana are the Missouri and Yellowstone Rivers. The majority of study area streams are tributary to the Yellowstone River, which flows northeasterly through the center of the area. Most of the small, upland drainages are ephemeral, flowing only during periods of direct runoff from rainfall or snowmelt. Consequently, stream channels of small drainages are dry during much of the year. Perennial streams in the area usually drain large areas and receive sufficient ground-water recharge to sustain base flows. However, irrigation withdrawals along these tributaries may largely deplete surface-water flows during the late summer.

METHODS FOR DETERMINING SEDIMENT YIELDS

Several methods are available for determining sediment yields from a basin. The three most common methods are: (1) Reservoir sedimentation surveys, (2) sampling of suspended sediment at streamflow-gaging stations, and (3) indirect estimation based on physical characteristics of a basin. Each method has advantages and limitations that must be considered in assessing its adequacy in representing long-term sediment losses from an area. A brief description of each of the three methods follows.

Reservoir sedimentation surveys

The amount of sediment transported out of a basin can be determined by measuring the volume of sediment deposited in a reservoir. By probing through the bottom sediments with a spudding tool, the interface between the deposited sediment and the original ground surface can be identified. Comparison of the original contours of the reservoir with present contours gives a measure of the total volume deposited since construction (Peterson, 1962). The volume of sediment deposited represents a reduction in reservoir storage capacity. This volume divided by the period of sediment accumulation, in years, gives the mean annual basin sediment discharge, usually expressed in acre-feet. To enable comparison of sediment discharges between study basins, sediment yield is computed by dividing mean annual sediment discharge by drainage area size, and is expressed in acre-feet per square mile.

To evaluate the reliability of sediment-yield estimates derived from reservoir surveys, several factors need to be considered. First, the age of the reservoir must be known to enable determination of a mean annual yield. Generally, an age of at least 10 years is necessary for a reliable indication of long-term average sedimentation rates. In addition, knowledge of the reservoir's trap efficiency can provide useful information for making adjustments to the measured sediment volume. If the reservoir overflows frequently, some of the suspended sediment will pass through without being deposited. However, most of the study reservoirs are located on ephemeral streams and few were observed to overflow. Consequently, any amounts of sediment escaping were probably very small compared to the total contribution.

Suspended-sediment sampling in streams

The procedure commonly used to estimate basin sediment yields at streamflow-gaging stations is to periodically measure the suspended-sediment concentration by collecting samples of the water-sediment mixture flowing down the channel. A concurrent measurement of water discharge is also necessary. Multiplying the sediment concentration by the amount of streamflow and a unit conversion factor gives a sediment discharge, usually expressed in tons per day. A relationship describing how sediment discharge varies with streamflow can be defined by plotting the concurrent measurements and drawing a sediment-rating curve. Flow-duration data available from streamflow records can be used with the sediment-rating curve to determine sediment discharges for specified percentages of time, which can be summed to obtain a mean annual sediment discharge for the period of record. On some streams, daily sediment samples are collected, which enables a calculation of average daily sediment concentration. These data can be combined with daily streamflow data to determine daily sediment discharges, which can be summed to obtain an annual discharge (Porterfield, 1972). Sediment discharge, in tons, can be converted to volume form (usually expressed in acre-feet) by either measuring or assuming an average density for the sediment. Mean annual yields are obtained by dividing the mean annual sediment discharge by drainage area.

Sampling sediment concentrations in streams during various runoff conditions gives insight into sediment-transport processes that is impossible to obtain with other methods. However, a wide range of hydrologic conditions needs to be sampled to define a reliable relationship between sediment discharge and streamflow. A well-defined relationship generally requires that streamflow records and sediment samples be collected for a long period of time to ensure adequate coverage of infrequent flows. Collecting samples during high flows is especially important, because such events commonly carry the bulk of the sediment transported during the year in the smaller drainages.

Because most stream sampling programs measure only the suspended part of the total sediment load, adjustments are necessary to account for the unmeasured load (bed load) if a total sediment yield is desired. Several methods are available for calculating the unmeasured component of total load. Although not discussed here, detailed descriptions can be found in Colby (1957) and Colby and Hubbell (1961). At low flows, most streams in eastern Montana lack the hydraulic capacity to move large amounts of coarse sediments, and the bed load is generally assumed to be a small fraction of the total load. At high flows, however, the bed load may constitute a significant percentage of the total transported sediment. Sediment data for streams in this report have not been adjusted for the unmeasured load. Therefore, reported sediment yields estimated from stream sampling represent only the suspended fraction of the total sediment yield.

Indirect estimation

When direct measurements of sediment deposition or transport are not available, indirect methods can be applied to estimate sediment yield from a basin. Three indirect methods commonly used are: (1) Estimation of gross erosion and a sediment-delivery ratio, (2) the Pacific Southwest Inter-Agency Committee (PSIAC) method of rating erosion factors, and (3) regression equations which relate basin characteristics to sediment yield. A brief description of each method follows.

In the first method, mean annual gross erosion, from all sources, is determined for the watershed upstream of the point where the yield estimate is needed (Renfro, 1975). Types of soil erosion to be considered include sheet and rill erosion, channel erosion (gullies, streambed, and bank erosion), and mass wasting (landslides and soil creep) from hillslopes or disturbed areas.

A widely used procedure for estimating sheet and rill erosion is the Universal Soil Loss Equation (USLE) as described by the U.S. Department of Agriculture (1972). This equation relates the rate of sheet and rill erosion to a number of major controlling factors such as soil type, slope, and rainfall. Because of the wide variability of watershed characteristics over short distances, the equation is best applied to small, relatively homogeneous areas. Channel erosion is commonly determined by periodic cross-sectional onsite surveys or by a series of aerial photographs from which the increase in channel volume with time is estimated. Soil loss from mass wasting is difficult to evaluate. Because it is frequently a short-lived event, it may have little effect on long-term sediment yields. Estimates of mass wasting are made by measuring the change in soil depth, with time, by pins or transects.

Once the total amount of erosion occurring within a basin has been determined, the next step is to estimate the proportion of the eroded materials that is actually transported from the basin. Some of the eroded sediment is deposited as colluvium at the base of slopes, as alluvium in flood plains and channels, and in reservoirs. Sediment yield from a watershed is, therefore, dependent on the percentage of eroded sediment that is ultimately lost from a basin. This percentage, which varies with the transporting efficiency of the drainage system, is the conveyance factor or sediment-delivery ratio. The sum of erosion from all sources, multiplied by the appropriate sediment-delivery ratio, gives a basin sediment yield.

To determine a sediment-delivery ratio, the sediment yield at a given point in the watershed and the total amount of erosion upstream from that point must be known. Where such information is available, a sediment-delivery ratio can be easily calculated by dividing the sediment yield by the gross erosion. However, both erosion rates and sediment yields usually are not available for most watersheds. Consequently, sediment-delivery ratios are commonly estimated from regionalized curves such as those developed by Roehl (1962), which relate delivery ratios to drainage area, stream length, topographic relief, or other physical characteristics. Because sediment-delivery ratios are generally estimated from limited data outside the study area, their accuracy for use in specific basins is uncertain.

A second indirect method (PSIAC) developed by the Pacific Southwest Inter-Agency Committee (1968) relates nine basin factors to erosion potential, which is used in determining the sediment-yield classification for a watershed. The factors are (A) geology, (B) soils, (C) climate, (D) runoff, (E) topography, (F) ground cover, (G) land use, (H) upland erosion, and (I) channel erosion/sediment transport. Each factor is assigned a numerical value from a rating chart. Descriptive terms for three sediment-yield levels (high, moderate, low) for each factor are used to select the numerical value. Summing the rating chart values for the nine factors defines a rating classification for determining the average annual sediment yield. Although this method can be applied to basins of various size, the rating of erosion factors is subjective and results may vary widely.

A third indirect method for estimating sediment yields at specific sites is development of regression equations based on the relationship of measured sediment yields to basin characteristics such as drainage area, topography, streamflow characteristics, climate, and soils (Jordan, 1979). Such predictive equations generally apply to limited areas having similar physiographic and hydrologic characteristics. The compilation of data for selected basin characteristics can range from detailed onsite measurements to approximate values obtained from maps or other published sources. This study utilizes the latter approach in an attempt to provide an easily applicable technique for estimating sediment yields from small, ungaged watersheds in eastern Montana.

SUMMARY OF SEDIMENT-YIELD DATA

The results of a search for sediment-yield data are summarized in tables 5 to 7 (Supplemental Data at back of report). Data for 121 sites have been compiled from studies conducted by various Federal, State, and private agencies. Information presented in this summary is intended to provide baseline data on erosion and sedimentation in eastern Montana. This data base will be useful to land-management agencies requiring information on sediment yields for a wide geographic area.

To simplify organization of the data, the tables have been separated by the methods used to determine sediment yield. Each of the 121 sites is identified by a map number, which refers to its location in figure 1. Within each table, the study sites are listed in downstream order. Dashes in columns of the table signify that data were unavailable or that the column was not applicable for the site. The "Reference" column cites the publication in which the data are published. If the data are unpublished, the reference is listed as a written communication along with the individual or agency supplying the information.

ESTIMATING SEDIMENT YIELDS FROM SMALL, UNGAGED WATERSHEDS

The second objective of this report is to attempt to develop empirical methods for estimating sediment yields from small, semiarid watersheds in eastern Montana lacking runoff data. If mathematical equations can be shown to satisfactorily predict long-term mean annual sediment yields, agencies responsible for land-management decisions will have a useful tool for estimating sediment yield from specific basins.

Approach concepts

Sediment yield varies temporally and spatially within stream systems. These variations are sometimes large and are a result of many complex processes controlled primarily by geology, physiography, and climate. Many of the controlling processes of sediment production and transport are poorly understood and some may still be unidentified.

The approach used in this study was to examine various physical, climatic, and hydrologic factors to determine their effectiveness in describing observed variations in sediment yields between basins. Empirical equations for estimating sediment yields were developed by multiple regression techniques that related measured sediment yields to selected basin characteristics. The basin characteristics examined consisted of variables that could be measured readily from maps or obtained from published sources. A practical benefit of such an approach is that estimates can be derived without collecting onsite data. Although detailed onsite data might improve the accuracy of sediment-yield estimates, the need for such accuracy must be weighed against the cost required to obtain the data.

Prior to a statistical analysis relating sediment yield to selected basin characteristics, available sediment-yield data were evaluated to determine their suitability in developing predictive equations. A primary consideration was the relative accuracy of the various methods by which sediment-yield determinations were made. In addition, an important criterion was the availability of records of sufficient length to reliably characterize long-term average conditions of runoff and erosion.

Sediment yields derived from calculation of sediment discharge obtained from stream samples were not used in regression analysis, owing to the generally short periods of sediment record and the fact that such records usually represent only the suspended part of the total sediment load. Sediment yields determined by indirect estimation were also eliminated from consideration because of the somewhat subjective nature of some erosion-estimate methods and the uncertainty of estimated delivery ratios.

Sediment yields determined from reservoir sedimentation surveys were considered to be the best data available for establishing relationships with basin characteristics. These data were derived from direct volumetric measurement of deposited sediment and are the most representative of a basin's total sediment yield. In addition, the period of sediment accumulation for most of the surveyed reservoirs exceeded 10 years; therefore, the data better reflect long-term climatic conditions. In this study, a criterion for a minimum length of record was arbitrarily specified at 5 years.

No attempt was made to select reservoirs having concurrent periods of sediment accumulation. By not having a common base period for all the reservoirs, the sediment yields can be considered to represent random sample data. Such data will commonly provide a better description of long-term expectancy than data for a concurrent base period. Although randomly distributed data may result in a larger standard error in a regression relation, this result is preferable to the bias that may be introduced by use of a base period if sediment yield during the base period is either smaller or larger than the long-term average (Thomas and Benson, 1969).

The equations presented in this report were developed using data from small basins having drainage areas less than 2 square miles. Because data on sediment accumulation rates in reservoirs having drainage areas greater than 2 square miles were limited, these sites were omitted from regression analysis. If included, data from these few sites might have a disproportionately large effect on the results and thereby produce unrepresentative regression coefficients. In addition, large drainage basins commonly exhibit a large variety of morphological characteristics; consequently, sediment transport may vary widely throughout the basin. Such variability makes it difficult to reliably quantify sediment yield on a unit-area basis, as the total yield from the basin is mathematically assumed to be uniformly derived from the entire drainage. In reality, however, much of the sediment yielded from a large basin may be derived from source areas of limited extent. Also, the increasing occurrence of aggradational features common in the downstream reaches of larger basins may mask actual sediment loss from upland areas. In contrast, smaller basins consist of generally uniform topographic features throughout the watershed and, in most instances, are located within a single lithologic unit. Therefore, reported yields are probably representative of the entire basin.

Because land use in most small watersheds of eastern Montana consists primarily of livestock grazing, measured sediment yields are assumed to represent natural to moderately disturbed conditions. Two small basins in the Armells Creek drainage were the only reservoir sites where data existed on post-mining, disturbed land. Consequently, these sites were omitted from regression analysis, owing to a lack of information from other basins where surface mining had occurred.

Basin characteristics

A basin characteristic is a numeric value representing a physical, climatic, or hydrologic feature of the drainage basin under consideration. The basin characteristics evaluated in this report include sediment yield and selected characteristics that are conceptually related to processes involved in the production and transport of sediment. Because of the large number of potential variables, basin characteristics examined as independent variables were generally limited to those that could be easily enumerated from existing maps or data sources.

Ten basin characteristics were selected for evaluation as independent variables in this study. Data sources and methods of computing each basin characteristic are discussed in the following sections. Values of basin characteristics are tabulated in table 8 (Supplemental Data at back of report) for each of the 61 reservoir study basins utilized in the regression analyses.

Sediment yield

The dependent variable sediment yield (*SEDYLD*), is the total volume of sediment transported from a watershed during a specified period of time, per unit of drainage area. Mean annual sediment yield, in acre-feet per square mile of drainage area, was determined by reservoir sedimentation surveys conducted onsite by the method previously described. The data were provided by the organizations or individuals listed in the "Reference" column of table 5.

Drainage area

Drainage area (*DA*) for a specific point on a stream is that area enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into the stream above the specified point. Drainage area, in square miles, was usually calculated by the agency providing the reservoir sedimentation data. When not provided, drainage area can be obtained by planimetering along the basin drainage divide on a U.S. Geological Survey 7-1/2 minute topographic map.

Meaningful comparisons of sediment yields between study basins require an accurate assessment of the noncontributing parts of the drainage area. Drainage areas upstream from either impoundments or other structures that effectively trap or divert sediment from the study reservoir need to be excluded from reported drainage area. For small basins, the amount of noncontributing area is generally negligible because the reservoir site is commonly near the headwaters. However, reservoirs in larger basins may have a significant amount of noncontributing area which, if included in the reported drainage area, could result in an underestimation of sediment yields.

Drainage density

Drainage density (*DD*), in miles per square mile, is a topographic index that is considered to represent surface texture. Drainage density was calculated from 7-1/2 minute topographic maps by dividing the length of all discernable stream channels, in miles, by drainage area, in square miles. Because some small first-order channels may have been overlooked, values for drainage density may be slightly underestimated. This source of error is probably negligible, however, because of the generally limited extent of first-order tributaries compared to higher-order channels.

Relief-length ratio

Relief-length ratio (*RL*) is a topographic index that takes into account the vertical component of surface texture. Relief-length ratio is a dimensionless index obtained by dividing the difference in elevation between the reservoir spillway and the headwater divide, in feet, by the length of the basin, in feet. The relief, as measured, does not include abnormally high points on the divide, and the length is measured essentially parallel to the main drainage channel within the basin. Surface elevations and basin lengths were determined from 7-1/2 minute topographic maps.

Width-length ratio

The width-length ratio (*WL*) provides some indication of general basin shape. Basin shape, in turn, can be related to the relative proximity of upland sediment sources to the main channel and the corresponding potential for eroded sediments to be transported or deposited en route. Basin width was determined by dividing drainage area, in square miles, by the channel length parallel to the main stream, in miles. The width-length ratio, which is dimensionless, was then computed by dividing basin width by the parallel channel length.

Meander ratio

Meander ratio (*MR*) is a measure of the sinuosity of the main stream channel. Meander ratio is a dimensionless index that gives insight into the aggradational characteristics of the main drainage channel by representing channel gradient and the relative resistance to flow and sediment transport. Meander ratio is computed as the ratio of the main channel length, in miles, to the length of the valley parallel to the main channel, in miles.

Forest cover

Forest cover (*FC*) can be used as a vegetative index to assess the relative degree of soil protection afforded by a reduction in raindrop impact, increased infiltration, and soil stabilization by roots. The index of forest cover used in this study is the percentage of total drainage area shown as forested on 7-1/2 minute topographic maps. This value was computed by planimetering the areas shaded green on the maps, and then dividing by the total drainage area.

Mean annual precipitation

Mean annual precipitation (*MAP*), in inches, is a measure of the amount of water supplied to a drainage basin and is a useful index for indicating potential runoff characteristics or vegetative cover. Mean annual precipitation for reservoirs having periods of sediment accumulation of 30 years or more was estimated from precipitation maps (U.S. Soil Conservation Service and Montana Department of Natural Resources and Conservation, 1977). Precipitation values for reservoirs having less than 30 years accumulation were calculated directly from climatological data (U.S. Department of Commerce, issued annually) corresponding to the years of sediment accumulation.

Streamflow magnitudes

The transport of sediment is controlled largely by a basin's streamflow characteristics; therefore, the magnitude of mean annual flows or frequently recurring floods may serve as an index of potential sediment yields. Stream discharges, in cubic feet per second, representing mean annual flow (*MAF*), and peak discharge magnitudes corresponding to 2-year (Q_2) and 5-year (Q_5) recurrence intervals were determined for the drainage basin of each reservoir. Equations for determining streamflow magnitudes have been developed for specific areas in Montana by multiple regression, utilizing basin characteristics such as drainage area, mean annual precipitation, mean basin elevation, and percent forest cover. A single equation for mean annual flow developed by R. J. Omang and Charles Parrett (1984) is applicable for the entire study area. Separate equations for estimating 2-year and 5-year peak discharges presented in Parrett and Omang (1981) are applicable for the area north (East-Central Plains Region) and south (Southeast Plains Region) of the Yellowstone River. These equations also include a geographical factor obtained from figure 2. Streamflow equations for the study area are as follows:

Flow condition		Equations	Standard error (percent)
MAF	=	$0.00013\, A^{0.99}\, P^{2.69}\, (F+10)^{-0.59}$	51
		East-Central Plains Region	
Q_2	=	$117\, A^{0.56}\, (E/1000)^{-1.50} G_f$	77
Q_5	=	$402\, A^{0.52}\, (E/1000)^{-1.42} G_f$	58
		Southeast Plains Region	
Q_2	=	$360\, A^{0.59}\, (F+10)^{-0.98} G_f$	105
Q_5	=	$1{,}010\, A^{0.58}\, (F+10)^{-0.99} G_f$	77

where: A is drainage area,
P is mean annual precipitation,
E is mean basin elevation,
F is percent forest cover, and
G_f is geographical factor.

For comparative purposes, stream discharges were divided by drainage area, in square miles, to give a unit-area streamflow, in cubic feet per second per square mile. These units of discharge are presented in table 8.

Multiple-regression analysis

Multiple-regression analysis was used to define the variation in observed sediment yields as a function of the previously discussed basin characteristics. Multiple regression provides a mathematical equation of the relation between a single dependent variable and two or more independent variables. The general form of a multiple-linear regression is

$$Y = a + b_1X_1 + b_2X_2 +. . . b_nX_n \qquad (1)$$

where:

Y is the dependent variable (sediment yield),
the X's are the independent variables (basin characteristics),
a is the regression constant,
the b's are regression coefficients, and
n is the number of basin characteristics tested.

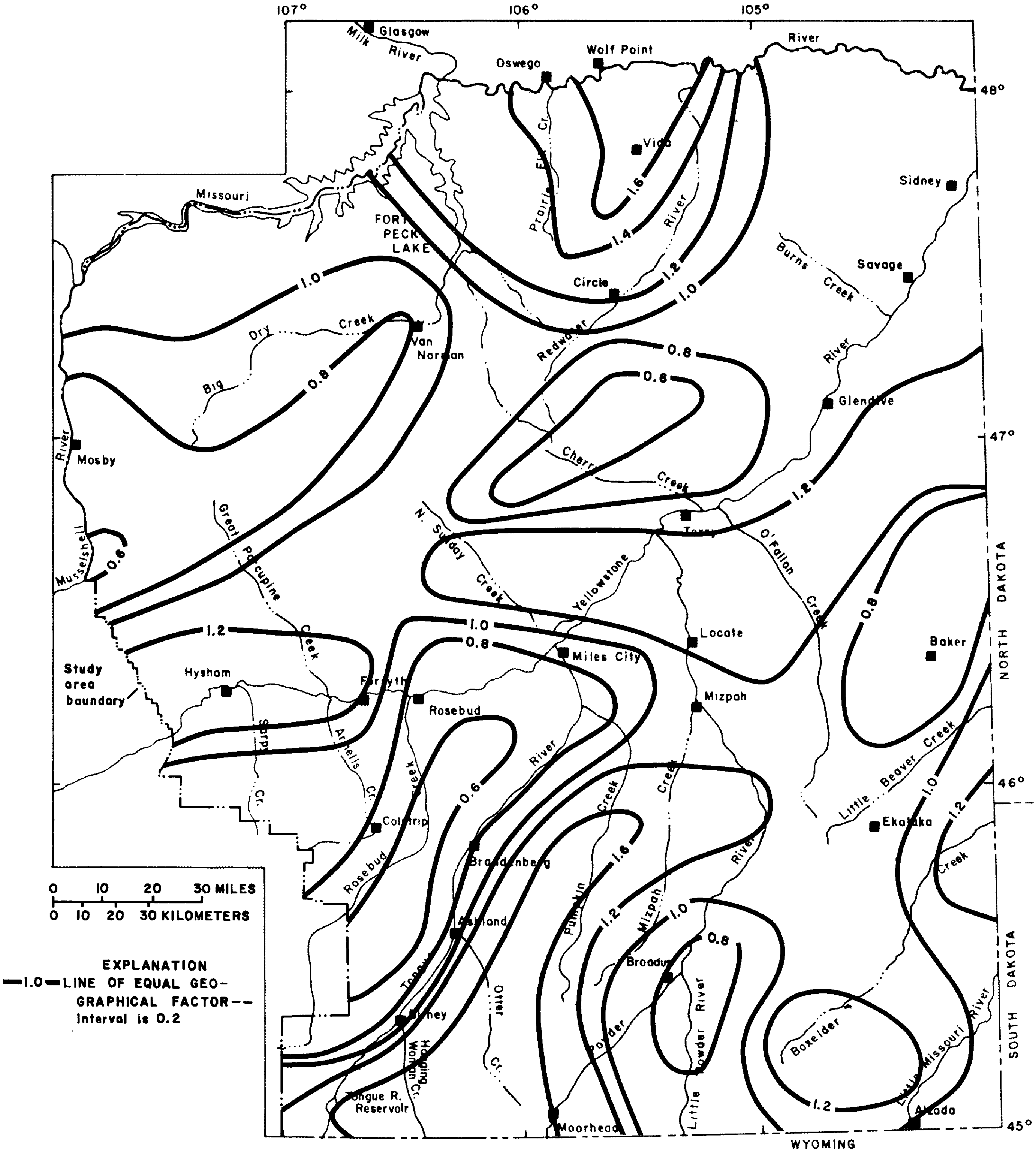


Figure 2.--Geographical factors (G_f) for streamflow equations (from Parrett and Omang, 1981).

Many studies have shown the relationship between hydrologic variables to be nonlinear. However, linear relationships can sometimes be obtained if values of the variables are transformed to logarithms. The general form of a log-transformed regression is

$$\log Y = \log a + b_1 \log X_1 + b_2 \log X_2 + \ldots b_n \log X_n \tag{2}$$

An equivalent form of equation 2 is

$$Y = a\, X_1^{b_1}\, X_2^{b_2} \ldots X_n^{b_n} \tag{3}$$

Because the logarithm of zero is undefined, a constant of 1.0 was added to values of percent forest cover prior to log transformation to avoid the use of zeros for unforested basins. Methods of computing regression constants and coefficients are explained by Riggs (1968). A system of statistical computer programs available through SAS Institute, Inc. (1979) was used to transform variables, compute regression coefficients, and perform various statistical tests.

Evaluation of regression equations

Selection of the regression equation that provides the best estimate of sediment yield is based on statistical tests that are used to evaluate the results of various combinations of basin characteristics. Selecting the most significant basin characteristics for inclusion in the regression equation required that the following statistical conditions were met:

1. Each basin characteristic was statistically significant at the $\alpha = 0.05$ level according to the "Students <u>t</u>" test of significance. This test implies that, if significant, there is a 95 percent probability that the observed relationship would not occur by chance alone.

2. From a test of all possible combinations of basin characteristics, the equation selected (a) had the smallest standard error of estimate and (b) explained the greatest percent of variation in observed sediment yields. The standard error of estimate, which is a measure of the accuracy of the regression relation, is a range of error about the observed values within which about two-thirds of the estimated values will occur. When the dependent variable is in logarithmic form, the standard error (in log units) is typically reported as a percentage, rather than as a range of values. The percent of variation in sediment yields explained by the independent variables is obtained by multiplying the coefficient of determination (R^2), which is the square of the multiple-correlation coefficient, by 100. One hundred percent of explained variation would indicate a perfect estimation, whereas zero percent would indicate that no linear relationship exists. The STEPWISE/MAXR procedure provided by SAS compares all combinations of independent variables and determines the best one-variable equation, two-variable equation, and so forth based on the maximum improvement of R^2.

3. The various basin characteristics used in the regression equation were not highly related among themselves. Violation of this criterion can lead to

unstable values for the regression coefficients and create difficulties in interpreting the effectiveness of independent variables included in the equation (Thomas and Benson, 1969). A measure of the linear relationship between two independent variables is given by the correlation coefficient where a value of 1.00 or -1.00 means perfect correlation, and a value of 0 means complete independence (no linear relationship). Basin characteristics with correlation coefficients greater than 0.5 need to be evaluated closely; however, significant errors in regression coefficients may not occur unless correlation coefficients are 0.8 or larger (Lystrom and others, 1978).

4. Residuals (difference between the observed and predicted values of the dependent variable) did not deviate significantly from a normal distribution and exhibited a generally uniform variance throughout the range of definition.

In addition to the above considerations, the final selection of regression equations was based on an assessment of the relative reduction in the standard error and increase in R^2 of each model. If, for example, a four-variable equation resulted in only a slight improvement in the value of R^2 over a three-variable equation, then the equation having the least number of variables would be chosen for ease of application. Of course, the practical advantage in using fewer variables would need to be judged with respect to the possible increase in the standard error of estimate. Careful evaluation of this somewhat subjective process ensures that accuracy is not compromised.

Limitations in the application of regression equations

Application of the regression equations and interpretation of results are subject to several limitations. These limitations, as outlined below, need to be considered for realistic assessment of regression-derived estimates.

1. Regression equations developed from this study are limited to estimating sediment yields only for small basins (less than 2 square miles) within the study area and possibly for adjacent areas having similar physiographic and hydrologic characteristics. Also, the regression equation cannot be correctly applied if it is extrapolated outside the range of data used in its development.

2. The regression equations define only the effects of the basin characteristics that were tested and found to be significant for each equation. Other untested variables may increase the percent of explained variation in sediment yields. However, no matter how well the regression line fits the data, it does not necessarily indicate a cause and effect relationship between the independent and dependent variables. Both may be affected by some other factor, which has not been examined or cannot be readily measured.

3. Statistical tests alone do not ensure the acceptability of regression equations. Conceptual knowledge of the processes of sediment production and transport can serve as a basis for evaluating, in realistic terms, whether or not the regression equations are valid in their implied relationships. Relationships that conflict with intuitive understanding

or regression coefficients with seemingly incorrect signs may indicate an equation of limited usefulness.

Data segregation

Regressions utilizing data from all reservoirs initially were examined to determine if a single equation for the entire study area could be used to estimate sediment yields from basin characteristics. Results indicated that the prediction capability was insufficient for practical use. Therefore, an attempt was made to improve regression results by segregating reservoirs into distinct groups that would exhibit more uniform relationships between sediment yield and basin characteristics.

A means to geographically group reservoirs by plotting regression residuals on the map and delineating areas having similar values was tried, but no discernible distribution patterns could be identified. Consequently, an attempt was made to segregate reservoirs on the basis of physical basin properties that are conceptually related to sediment yield and that cannot be adequately represented by simple numeric indexes. Reservoirs were thereby grouped into similar physical regimes of geology, soils, and vegetation/soil complex. Regression analyses were then performed separately on each group. The following sections describe the three segregation schemes tested in this study.

Geology

Surface geologic formations are the parent materials from which soils are formed through weathering and biochemical breakdown by plants. Because of the direct association between geology and soil type, the variation in sediment yields might be explained to some extent by the type of parent geologic material underlying the reservoir's drainage basin. Geologic materials directly affect basin morphology by means of erodability, and indirectly affect sediment loadings through weathering products. Geologic formations and their areal distribution are described on a geologic map of Montana compiled by Ross and others (1955). For basins overlying the Paleocene Fort Union Formation, a delineation of the various members was obtained from a hydrogeologic map of the Fort Union Coal Region (Stoner and Lewis, 1980).

Two means of grouping reservoirs on the basis of similarity of geologic formations underlying the basins were tested. The first involved segregation on the basis of whether the parent material was composed primarily of shale or sandstone. The second means of grouping was by formation age (either Tertiary or Cretaceous). The formations underlying the study basins are listed on the adjacent page in correct stratigraphic sequence:

	Geologic unit and abbreviation		Predominant lithology
TERTIARY	Fort Union Formation		
	Tongue River Member (Tft)		Sandstone
	Lebo Shale Member (Tfl)		Shale
	Tullock Member (Tftu)		Sandstone
CRETACEOUS	Hell Creek Formation (Kh)		Sandstone
	Fox Hills Sandstone (Kf)		Sandstone
	Bearpaw Shale (Kb)	Pierre Shale (Kp)	Shale
	Claggett Formation (Kcl)		
	Niobrara Formation (Kn)		Shale
	Carlile Shale (Kc)		Shale
	Belle Fourche Shale (Kbf)		Shale

The abbreviations representing the geologic formations are given in table 8 under the heading *GEO*.

Soils

Soil characteristics are considered to be strongly related to sediment yield owing to the variability in particle texture, infiltration capacity, and aggregation properties. Because of the difficulty in assigning numeric values to specific soil characteristics without detailed onsite data, reservoirs were segregated into groups having generally similar soil characteristics within their basins. Descriptions of soils and their areal distribution are presented in a general soils map of Montana (U.S. Soil Conservation Service, 1978). Although more detailed, onsite soils data may provide a better index of erosion potential, such data are not always available. Therefore, general soil properties were used as the basis for reservoir grouping.

In this study, soil orders and great groups predominant in each reservoir's drainage basin were determined. The Torriorthent great group of the Entisol-Aridisol soil orders was predominant in most basins. Consequently, the limited variability in general soil types among basins did not provide an adequate distribution of data from which to form distinct groups. A more uniform distribution of reservoir sites existed when segregation was based on soil moisture regime. Soil moisture regime is an index of the amount of water that enters the soil profile and the amount that percolates through, or is held and used by plants. Therefore, soil moisture regimes provide an indication of average soil moisture conditions by integrating climatic factors with the physical factors of slope, aspect, plant cover, permeability, and water table. Soil moisture regime is a major criterion for separating soil orders and great groups into the various units delineated on the general soil map of Montana (U.S. Soil Conservation Service, 1978).

Reservoir sites in the study area were classified as: (1) sites having an "aridic" soil moisture regime and (2) sites whose soil moisture regimes include either an "ustic" or "aquic" component. Aridic soil moisture regimes are described as arid and semiarid and are generally dry more than one-half of the growing season. Soils of the ustic moisture regime are described as semiarid or subhumid; although they have limited soil moisture, it is present primarily during the growing season. Soils of the aquic moisture regime are described as wet and are saturated by a seasonal or permanent high water table. The soil moisture regimes for each reservoir are presented in table 8 under the heading *SMR*.

Vegetation/soil complexes

The final method of data segregation tested by regression analysis was classification by vegetation/soil complex. A vegetation/soil complex represents a specific combination of soil and climatic conditions which, in turn, determines the capability of the area to support a distinct climax vegetation community. A climax vegetation community is the predominant composition of plant species capable of maintaining its population under the prevailing natural conditions of climate and soil. In many areas, the existing composition of plant species has deviated from that of the native climax community owing to grazing, insects, fire, or other land disturbances. However, because a vegetation/soil complex incorporates permanent features of the landscape such as soil (texture, depth, and permeability) and climate (precipitation, elevation, temperature, and exposure), it provides a means for integrating biotic and abiotic factors within a watershed. A combination of factors which includes plant cover, soil type, and climatic conditions would be expected to explain a significant amount of the variation in sediment yields among basins.

The vegetation/soil complex for each reservoir's drainage basin was determined from a climax vegetation map of Montana (Ross and Hunter, 1976). The area of the map pertaining to this study is shown in figure 3. The units delineated geographically on the map represent a generalization of climax plant communities based on soil properties and climate. The study area is primarily within the "Eastern Sedimentary Plains" geographical area, which includes 13 vegetation/soil complexes (map units 14-26). Also included is a small area of "Eastern Glaciated Plains" just south of the Missouri River. This area includes two vegetation/soil complexes (map units 1 and 2). In this study, the 15 complexes were segregated into three classes having generally similar soil and plant type. Each vegetation/soil complex and the segregation scheme utilized are described in table 9 (Supplemental Data at back of report).

Corresponding map units for each reservoir basin are presented in table 8 under the heading VS. No sites occurred within map units 1, 2, 15, 19, 22, 23, or 26. Future data from these complexes might serve to identify potential modifications to the proposed segregation scheme.

RESULTS AND INTERPRETATION

Evaluation of multiple-regression equations indicated that the best prediction capability (largest R^2 and smallest standard error) was obtained when reservoirs were segregated into groups based on vegetation/soil complex. Regression equations for vegetation/soil complexes A, B, and C are presented in table 1. Each of the independent variables is significant at the $\alpha = 0.05$ level. Although equations

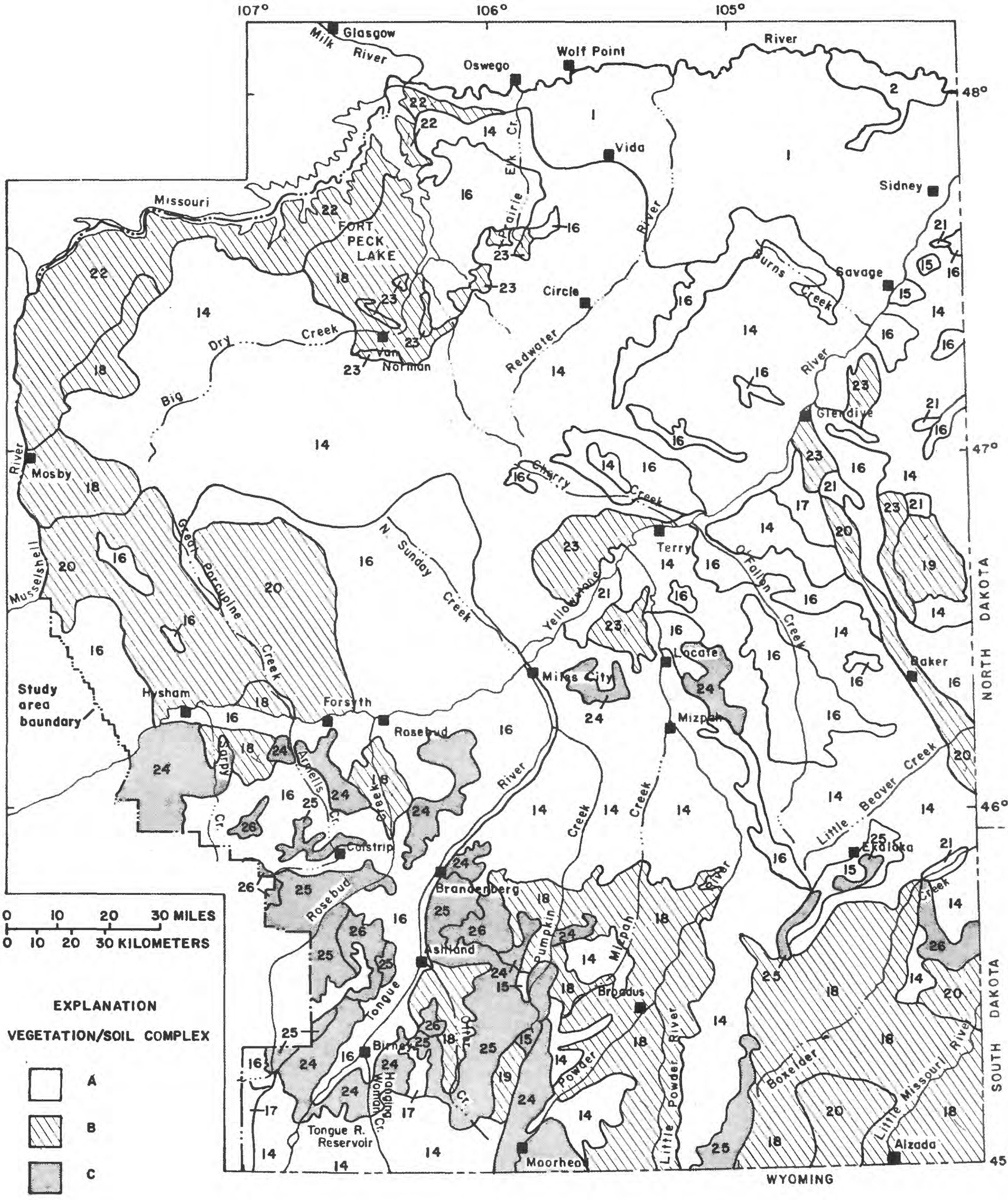


Figure 3.--Geographic distribution of vegetation/soil complexes A, B, and C.

for vegetation/soil complexes were superior to those developed for geology and soils, it is important to examine the adequacy of these equations in providing reliable estimates of sediment yield.

Table 1.--*Equations for estimating mean annual sediment yields from small, ungaged watersheds in eastern Montana*

Vegetation/soil complex	Equation	Number of sites	Coefficient of determination (R^2)	Standard error of estimate (percent)[1]
A	log SEDYLD = -3.18 - 4.23 log MR + 1.00 log Q_5	21	0.59	95
B	log SEDYLD = -0.130 + 0.095 DD - 1.15 MR	27	.71	71
C	log SEDYLD = -2.39 - 0.393 DA + 0.072 DD + 0.571 log Q_5	11	.96	20

[1]Standard error in log units converted to percent.

To illustrate the correlation between sediment yield and the individual basin characteristics tested in this study, a matrix of simple correlation coefficients is presented for each vegetation/soil complex (tables 2-4). Also incorporated in these matrices is the correlation between each of the basin characteristics, which was used to evaluate the degree of cross-correlation between the independent variables. None of the correlation coefficients for any two independent variables used in the regression equations exceeded 0.60, thereby indicating that cross-correlation did not have a significant effect on regression coefficients.

Table 2.--*Matrix of simple correlation coefficients between basin characteristics for reservoirs in vegetation/soil complex A*

	SEDYLD	*DA*	*DD*	*RL*	*WL*	*FC*	*MAP*	*MR*	*MAF*	Q_2	Q_5
SEDYLD	1.00										
DA	-.45	1.00									
DD	.24	-.26	1.00								
RL	-.02	-.14	.35	1.00							
WL	-.17	.58	-.32	-.13	1.00						
FC	-.28	.56	.28	.35	.48	1.00					
MAP	-.22	.20	-.07	.16	.39	-.01	1.00				
MR	-.63	.68	.12	.07	.37	.54	.30	1.00			
MAF	-.14	-.03	-.18	.04	.21	-.36	.91	.11	1.00		
Q_2	.49	-.66	.40	.15	-.22	-.43	.26	-.47	.38	1.00	
Q_5	.66	-.73	.39	.04	-.31	-.50	.02	-.60	.19	.93	1.00

Table 3.--*Matrix of simple correlation coefficients between basin characteristics for reservoirs in vegetation/soil complex B*

	SEDYLD	*DA*	*DD*	*RL*	*WL*	*FC*	*MAP*	*MR*	*MAF*	*Q2*	*Q5*
SEDYLD	1.00										
DA	-.31	1.00									
DD	.70	-.08	1.00								
RL	.26	-.10	.26	1.00							
WL	.18	-.12	.22	-.02	1.00						
FC	-.03	.06	.09	.37	.23	1.00					
MAP	.15	-.01	.26	-.11	-.18	.14	1.00				
MR	-.31	.40	.15	.08	-.09	.18	.27	1.00			
MAF	.30	-.11	.27	-.22	-.28	-.48	.71	.07	1.00		
Q2	.56	-.56	.31	.02	.03	-.40	.22	-.40	.45	1.00	
Q5	.59	-.59	.32	.03	.11	-.42	.09	-.43	.38	.98	1.00

Table 4.--*Matrix of simple correlation coefficients between basin characteristics for reservoirs in vegetation/soil complex C*

	SEDYLD	*DA*	*DD*	*RL*	*WL*	*FC*	*MAP*	*MR*	*MAF*	*Q2*	*Q5*
SEDYLD	1.00										
DA	-.60	1.00									
DD	.58	.01	1.00								
RL	-.02	.03	.50	1.00							
WL	-.51	-.19	-.83	-.25	1.00						
FC	-.10	-.11	.38	.74	-.27	1.00					
MAP	-.45	.05	-.23	.18	.49	-.03	1.00				
MR	-.57	.65	.09	.29	-.08	.11	.59	1.00			
MAF	-.18	.06	-.44	-.41	.59	-.75	.62	.19	1.00		
Q2	.57	-.58	-.29	-.59	.16	-.53	-.46	-.85	.17	1.00	
Q5	.57	-.58	-.29	-.58	.16	-.52	-.46	-.86	.17	.99	1.00

Several relationships indicated by correlation within the three reservoir groups probably are worth further discussion. Of the 10 independent variables tested, drainage area (*DA*), drainage density (*DD*), meander ratio (*MR*), and 5-year peak discharge (Q_5) were determined to be the most significant variables for inclusion in the regression equations. In support of the statistical tests of significance, these four variables generally were the most strongly correlated to sediment yield (*SEDYLD*) and exhibited similar relationships within each reservoir group. In contrast, the variables relief-length ratio (*RL*), width-length ratio (*WL*), mean annual precipitation (*MAP*), and mean annual flow (*MAF*) exhibited generally weak and inconsistent correlations with sediment yield among the three reservoir groups. This inconsistency may indicate that either these basin characteristics have no apparent relationship to sediment yield or underlying relationships are masked by other factors. One observation that seems contrary to intuition is that correlation coefficients between sediment yield and mean annual flow (*MAF*) are frequently of opposite signs compared to those for 2-year (Q_2) and 5-year (Q_5) peak discharges. It would seem logical to assume that streamflow characteristics, regardless of the mode of representation, would exhibit similar relationships with sediment yield or other individual basin characteristics. This inconsistency may indicate the need for further refinement of streamflow equations used in generating hydrologic basin characteristics.

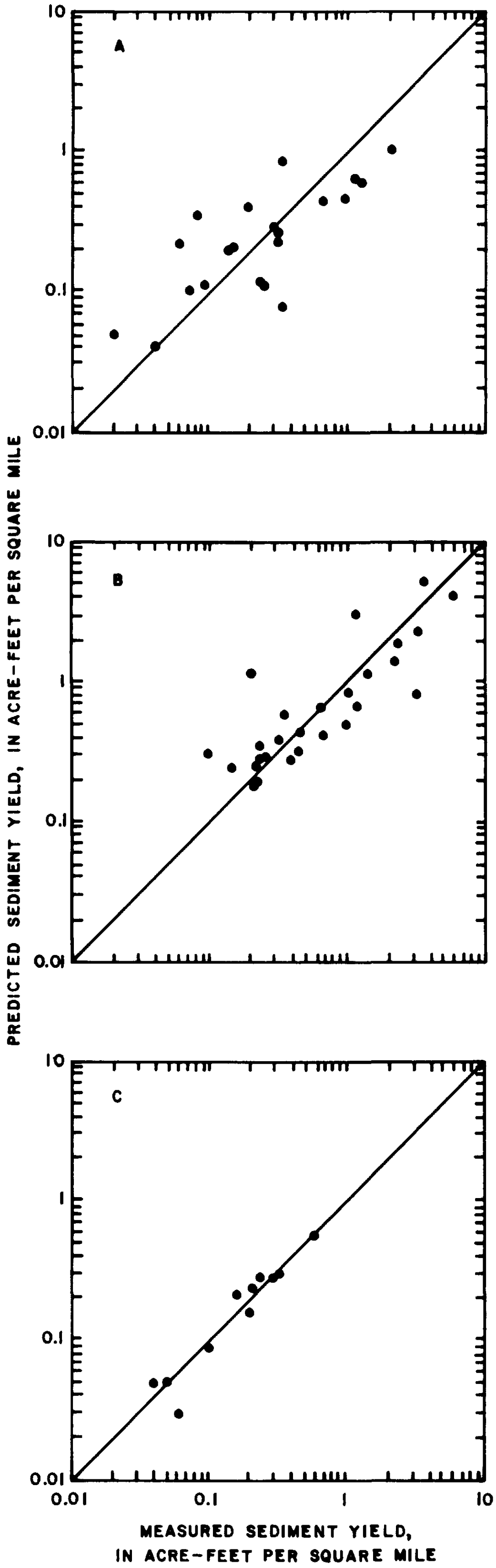
In addition to evaluating the amount of correlation among each of the independent variables, a test was performed to determine if the regression residuals were normally distributed. Overall normality of distribution of residuals is a basic criterion for regression analysis (Draper and Smith, 1966). A normality test was performed on residuals using the PROC UNIVARIATE procedure available in SAS. Residuals for each equation were found to be normally distributed, thereby satisfying the population assumption of normality. Also, examination of residual plots confirmed that residuals were generally of uniform variance throughout the range of definition.

From inspection of residual plots, it also was determined that two reservoirs in vegetation/soil complex B (reservoirs 38 and 59) were obvious outliers. These two reservoirs were subsequently removed from further regression analyses to eliminate possible effects resulting from unrepresentative values.

To illustrate how well the equations simulate actual values of sediment yield, values of predicted versus measured sediment yields were graphed (fig. 4). These plots can be compared to the 1:1 line of equality (solid line) to ascertain the relative deviation of predicted values from measured values. Tabulated values of measured and predicted sediment yields are also provided for practical evaluation of the predictive capability of each equation.

By comparison of the three graphs in figure 4, it is obvious that the equations for vegetation/soil complexes A and B have limited predictive capability, whereas the equation for complex C accurately simulates actual values. Vegetation/soil complex C is a mixed forest-grassland environment in which the loamy soils and plant communities presumably result in greater sediment stability. Because complex C exhibits less variation in sediment yields than complexes A or B, which are grassland environments, the prediction accuracy is considerably better. The equations presented in table 1 for complexes A and B have a tendency to underpredict at large sediment yields and overpredict at small sediment yields, as indicated by the distribution of points about the line of equality. This same observation was noted by Renard and Stone (1982) in their evaluation of five methods for estimating sediment yields. The reason for predicted sediment yields to consistently exhibit positive or negative deviations within a certain range of values is unknown, but may result from other untested variables that have a significant effect on sediment yield interacting with basin characteristics used in this study. Such trends may also be a phenomenon inherent in the least-squares method of line fitting.

Major factors that probably account for a significant amount of variation are runoff and vegetative condition of drainage channels. Because of the scope of this study wherein onsite data are not utilized, actual measurements of the above factors were not employed. The lack of observed runoff data required that streamflow magnitudes be estimated from regression equations relating flow to basin character-



Reservoir	Sediment yield Measured	Sediment yield Predicted	Reservoir	Sediment yield Measured	Sediment yield Predicted
		COMPLEX A			
2	0.24	0.12	34	0.94	0.47
4	.07	.10	40	.08	.35
9	.67	.44	42	.31	.27
10	.34	.85	43	.33	.08
16	.04	.04	44	.19	.40
17	.02	.05	45	.06	.22
18	.09	.11	47	2.02	1.02
24	.32	.32	48	.25	.11
25	.14	.20	50	.31	.26
30	1.16	.63	51	.15	.21
33	1.22	.61			
		COMPLEX B			
1	3.13	0.81	55	6.04	4.02
5	1.18	3.06	56	.45	.32
6	.26	.29	57	1.19	.66
20	.32	.38	58	.96	.48
21	.10	.31	60	1.39	1.13
22	.23	.28	61	.47	.43
23	.23	.35	62	3.27	2.26
29	.36	.58	63	.21	.18
37	2.29	1.39	64	3.72	5.19
39	.22	.19	65	.65	.42
41	.22	.25	66	.66	.65
52	.21	1.14	67	2.41	1.87
53	.15	.24	68	1.03	.81
54	.39	.28			
		COMPLEX C			
12	0.06	0.07	27	0.21	0.19
13	.10	.11	28	.20	.16
14	.24	.20	35	.30	.28
15	.04	.05	36	.58	.77
19	.05	.05	46	.16	.15
26	.33	.30			

Figure 4.--Relationship of measured mean annual sediment yields to predicted mean annual sediment yields for vegetation/soil complexes A, B, and C. Solid line is 1:1 line of equality.

istics. Considering the generally large standard errors of the available runoff equations, it is not surprising that incorporation of such poorly defined runoff estimates into sediment yield equations would result in similar poorly defined relationships.

The vegetative condition of drainage channels could also have a significant effect on the magnitude of sediment yield, as this factor would have a large bearing on sediment losses from channel sources. Unvegetated drainage channels would tend to be unstable and would yield larger amounts of sediment than a grassed or partly vegetated channel. Because onsite inspections of channel condition were not utilized, it is logical to assume that this unmeasured factor may be responsible for some of the unexplained variation in the regression relations. Evaluation of the density of raw channels in a basin, either by inspection of large-scale aerial photographs or a single onsite visit, would presumably improve the prediction capability of equations presented herein.

An additional difficulty in attempting to describe the variation of observed sediment yields by analyzing general relationships with basin characteristics is that discrete, and often localized, land disturbance that cannot be related to physical properties of the basin may have an overriding impact on sediment yield. Apart from the obvious soil disruption associated with surface mining, examples of sediment production leading to inconsistent relationships include road construction, plowing, fire and subsequent loss of vegetation, intense and localized rainstorms of rare occurence, and overgrazing. These conditions may lead to large amounts of sediment being eroded and eventually transported out of a basin. The result of these conditions is that sediment yields may vary widely, whereas values of basin characteristics computed for watersheds in similar environmental regimes commonly cluster within a narrow range. The true relationship between sediment yield and basin characteristics may, therefore, be masked by individual, short-term events. Such factors, however, would tend to exert less impact on rates of sediment loss in basins where measured sediment yield represents a long interval of time. The sediment lost during a short period of disruption would conceivably represent a small percentage of the total amount of sediment yielded from a basin over the years. Consequently, the longer the period of sediment record, the more closely measured sediment yields would be expected to represent conditions primarily controlled by natural sediment transport processes.

As data from additional reservoirs become available, improvement in the prediction of sediment yields can be expected. Data from additional sites could broaden the data base to include larger basins, better define observed relationships, provide greater areal distribution, and give insight into more effective data segregation. Further investigations could also reveal as-yet-untested variables which would explain a significant amount of variation in observed sediment yields. However, owing to the inherent variability of sediment yields resulting from the continuous interaction between accelerating and restraining forces on erosion, sediment-yield equations may be better suited to providing comparisons of relative magnitudes between basins rather than absolute values.

SUMMARY

Sediment-yield data for 121 sites in eastern Montana have been compiled for the purpose of establishing a regional data base. The available data include results of both local and regional studies conducted by various Federal, State, and private agencies. Methods used in the determination of mean annual sediment yields included reservoir sedimentation surveys, sampling of suspended sediment at streamflow-gaging stations, and indirect estimation based on physical characteristics of the basin. The watersheds for which sediment yields have been determined vary substantially in size and are distributed over a wide geographic area. The data summarized in this report can serve as a basis for illustrating regional variation and identifying areas where additional studies might be warranted.

A second objective of this study was to develop equations for estimating mean annual sediment yields from small, ungaged watersheds in eastern Montana. Measured sediment yields determined from reservoir sedimentation surveys were used in developing equations, as they were considered to be the most representative of long-term basin yields. Multiple-regression analysis was used to determine relationships between measured mean annual sediment yield (dependent variable) and selected basin characteristics (independent variables) of small watersheds having drainage areas less than 2 square miles. Values for basin characteristics were determined from maps or other published sources. Consequently, the equations developed in this study can be used without onsite data.

The basin characteristics used consisted of physical, climatic, and hydrologic properties considered to be conceptually related to the processes of erosion and sediment transport. The 10 basin characteristics tested as independent variables were drainage area, drainage density, relief-length ratio, width-length ratio, meander ratio, forest cover, mean annual precipitation, mean annual flow, 2-year peak discharge, and 5-year peak discharge. Drainage area, drainage density, meander ratio, and 5-year peak discharge were determined to be the most significant variables for inclusion in the regression equations. All independent variables used in the equations were significant at the $\alpha = 0.05$ level.

Evaluation of multiple-regression equations indicated that the best prediction capability [largest coefficient of determination (R^2) and smallest standard error] was obtained when reservoirs were segregated into groups based on the general vegetation/soil complex occurring in the basin. Three groups of reservoirs, representing vegetation/soil complexes A, B, and C, were formed and analyzed separately. The predictive capability of regression equations developed for each complex ranged from limited to good. Results of the regression analyses were: Complex A, R^2 of 0.59 and standard error of 95 percent; complex B, R^2 of 0.71 and standard error of 71 percent; and complex C, R^2 of 0.96 and standard error of 20 percent. Whereas the equation for vegetation/soil complex C accurately simulates observed values, equations of complexes A and B tend to underpredict at large sediment yields and overpredict at small yields.

The equations presented in this report are applicable for small drainage basins of 2 square miles or less within the study area and possibly in adjacent areas having similar physiographic and hydrologic characteristics. However, because of the inherent variability of sediment yields resulting from the continuous interaction between accelerating and restraining forces on erosion, the sediment-yield equations may be better suited to providing comparisons of relative magnitudes between basins rather than absolute values.

REFERENCES CITED

Colby, B. R., 1957, Relationship of unmeasured sediment discharge to mean velocity: American Geophysical Union Transactions, v. 38, p. 708-717.

Colby, B. R., and Hubbell, D. W., 1961, Simplified methods for computing total sediment discharge with the modified Einstein procedure: U.S. Geological Survey Water-Supply Paper 1593, 17 p.

Consolidation Coal Company, 1981, Baseline hydrological investigation for proposed CX Ranch Mine, Final report: v. 8, book 1, p. 100-102.

Dendy, F. E., and Champion, W. A., 1978, Sediment deposition in U.S. reservoirs, Summary of data reported through 1975: U.S. Department of Agriculture Miscellaneous Publication No. 1362, 84 p.

Draper, N. R., and Smith, H., 1966, Applied regression analysis: New York, John Wiley and Sons, Inc., 407 p.

Hadley, R. F., Frickel, D. G., Shown, L. M., and Miller, R. F., 1981, Methodology for hydrologic evaluation of a potential surface mine--East Trail Creek basin, Big Horn County, Montana: U.S. Geological Survey Water-Resources Investigations Open-File Report 81-58, 73 p.

Jordan, P. R., 1979, Relation of sediment yield to climatic and physical characteristics in the Missouri River basin: U.S. Geological Survey Water-Resources Investigations 79-49, 26 p.

Koch, Roy, Curry, Robert, and Weber, Mark, 1977, The effect of altered streamflow on the hydrology and geomorphology of the Yellowstone River Basin, Montana: Yellowstone River Impact Study, Technical Report No. 2, 163 p.

Lambing, J. H., 1983, Statistical analysis and evaluation of water-quality data for selected streams in the coal area of east-central Montana: U.S. Geological Survey Water-Resources Investigations Report 83-4224, 89 p.

Litke, D. W., 1983, Suspended sediment in selected streams of southeastern Montana: U.S. Geological Survey Water-Resources Investigations Report 82-4087, 52 p.

Lystrom, D. J., Rinella, F. A., Rickert, D. A., and Zimmerman, Lisa, 1978, Regional analysis of the effects of land use on stream-water quality--Methodology and application in the Susquehauna River basin, Pennsylvania and New York: U.S. Geological Survey Water-Resources Investigations 78-12, 67 p.

Montagne, Clifford, Munn, L. C., Nielsen, G. A., Rogers, J. W., and Hunter, H. E., 1982, Soils of Montana: Bozeman, Montana Agricultural Experiment Station Bulletin 744, 95 p.

Montco, 1981, Erosion and sedimentation: Permit application, v. 14, Appendix D, 31 p.

Omang, R. J., and Parrett, Charles, 1984, A method for estimating mean annual runoff of ungaged streams based on basin characteristics in central and eastern Montana: U.S. Geological Survey Water-Resources Investigations Report 84-4143, 15 p.

Pacific Southwest Inter-Agency Committee, 1968, Report on factors affecting sediment yield in the Pacific Southwest area: Water Management Subcommittee, Sedimentation Task Force, 10 p.

Parrett, Charles, and Omang, R. J., 1981, Revised techniques for estimating magnitude and frequency of floods in Montana: U.S. Geological Survey Open-File Report 81-917, 66 p.

Peterson, H. V., 1962, Hydrology of small watersheds in western States: U.S. Geological Survey Water-Supply Paper 1475-I, p. 217-356.

Porterfield, George, 1972, Computation of fluvial-sediment discharge: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chapter C3, 66 p.

Renard, K. G., and Stone, J. J., 1982, Sediment yield from small semiarid rangeland watersheds: Proceedings of the workshop on estimating erosion and sediment yield on rangelands, Tucson, Arizona, March 7-9, 1981, p. 129-144.

Renfro, G. W., 1975, Use of erosion equations and sediment-delivery ratios for predicting sediment yield: Oxford, Miss., U.S. Department of Agriculture, Agricultural Research Service Proceedings, Sediment-Yield Workshop, November 28-30, 1972, p. 33-45.

Riggs, H. C., 1968, Some statistical tools in hydrology: U.S. Geological Survey Techniques of Water-Resources Investigations, book 4, chapter A1, 39 p.

Roehl, J. W., 1962, Sediment source areas, delivery ratios, and influencing morphological factors: International Association of Scientific Hydrology, Publication No. 59, p. 202-213.

Ross, C. P., Andrews, D. A., and Witkind, I. J., 1955, Geologic map of Montana: U.S. Geological Survey, scale 1:500,000, 2 sheets.

Ross, R. L., and Hunter, H. E., 1976, Climax vegetation of Montana: Bozeman, Mont., U.S. Department of Agriculture, Soil Conservation Service, 64 p.

SAS Institute, Inc., 1979, SAS user's guide, 1979 edition: Raleigh, N. C., 494 p.

Stoner, J. D., and Lewis, B. D., 1980, Hydrogeology of the Fort Union coal region, eastern Montana: U.S. Geological Survey Miscellaneous Investigations Map I-1236, scale 1:500,000.

Thomas, D. M., and Benson, M. A., 1969, Generalization of streamflow characteristics from drainage basin characteristics: Washington, D.C., U.S. Geological Survey open-file report, 45 p.

U.S. Bureau of Land Management, 1982, Big Dry vegetation allocation: U.S. Department of the Interior Draft Environmental Impact Statement, 47 p.

U.S. Department of Agriculture, 1972, Procedure for estimating sheet and rill erosion on project areas: Soil Conservation Service Technical Release No. 51, 14 p.

U.S. Department of Commerce, issued annually, Climatological data, Montana.

U.S. Department of the Interior, 1975, Resource and potential reclamation evaluation, Otter Creek study site, Otter Creek coalfield, Montana: EMRIA Report No. 1, 234 p.

______1977a, Resource and potential reclamation evaluation, Bear Creek study area, West Moorhead coalfield, Montana: EMRIA Report No. 8, 259 p.

______1977b, Resource and potential reclamation evaluation, Hanging Woman Creek study area [Montana]: EMRIA Report No. 12, 309 p.

______1982, Resource and potential reclamation evaluation, Pumpkin Creek study area, Pumpkin Creek coalfield, Powder River County, Montana: EMRIA Report No. 21-78, 64 p.

U.S. Department of the Interior and Montana Department of State Lands, 1977, Proposed plan of mining and reclamation--East Decker and north extension mines, Decker Coal Company, Big Horn County, Montana: Final Environmental Impact Statement, v. 1, 871 p.

U.S. Soil Conservation Service, 1978, General soil map, Montana: Department of Agriculture, map 7-S-23899, scale 1:1,000,000, *in* Soils of Montana, Montana Agricultural Experiment Station Bulletin 744, plate.

U.S. Soil Conservation Service and Montana Department of Natural Resources and Conservation, 1977, Average annual precipitation, Montana, based on 1941-70 base period: Bozeman, Mont., 13 p.

SUPPLEMENTAL DATA

Table 5.--*Summary of reservoir sedimentation surveys*

[acre-ft, acre-feet; acre-ft/mi^2, acre-feet per square mile. Significant figures reported in table are same as given in reference.]

Map No. (fig. 1)	Reservoir	Major drainage basin	Subbasin	Location	Drainage area[1] (square miles)	Date of construction or initial survey (month-year)	Date of most recent survey (month-year)
1	Shaw	Musselshell River.	Sage Hen Creek.	sec. 10, T. 14 N., R. 31 E.	0.14	1971	06-80
2	Brackett	Big Dry Creek	Second Creek.	sec. 3, T. 16 N., R. 39 E.	.26	1939	06-80
3	McMullen Brothers	Timber Creek	Unnamed	sec. 30, T. 15 N., R. 46 E.	3.81	1960	1963
4	Chickie	Redwater River	Lisk Creek.	sec. 12, T. 15 N., R. 46 E.	.49	09-36	08-80
5	Dons	Great Porcupine Creek.	Acorn Creek.	sec. 30, T. 12 N., R. 37 E.	.23	07-53	07-80
6	Cornwell	Yellowstone River.	McGraw Coulee.	sec. 2, T. 6 N., R. 39 E.	.16	03-47	06-80
7	PO-008[2]	Yellowstone River.	Armells Creek.	sec. 3, T. 1 N., R. 41 E.	.30	1978	1979
8	PO-009[2]	Yellowstone River.	Armells Creek.	sec. 33, T. 2 N., R. 41 E.	.21	1980	1982
9	Barley	Yellowstone River.	Sand Creek.	sec. 10, T. 8 N., R. 43 E.	.18	04-47	07-80
10	Lockie	Yellowstone River.	Wilson Creek.	sec. 4, T. 7 N., R. 44 E.	.09	07-44	06-80
11	Tongue River.	Yellowstone River.	Tongue River.	sec. 13, T. 8 S., R. 40 E.	1,734	05-39	10-48
12	Prairie Dog NW.	Tongue River	Prairie Dog Creek.	sec. 4, T. 6 S., R. 40 E.	.74	1943	10-80
13	Prairie Dog SE.	Tongue River	Prairie Dog Creek.	sec. 4, T. 6 S., R. 40 E.	.30	[3]1943	10-80
14	Corral	Tongue River	Prairie Dog Creek.	sec. 7, T. 6 S., R. 41 E.	.26	1941	10-80
15	Jeffreys Prong.	Tongue River	Prairie Dog Creek.	sec. 21, T. 6 S., R. 41 E.	.62	1942	10-80
16	C	Hanging Woman Creek.	Trail Creek.	sec. 6, T. 9 S., R. 44 E.	.96	1937	08-76
17	E	Hanging Woman Creek.	Trail Creek.	sec. 33, T. 8 S., R. 44 E.	.87	1937	08-76

Period of sediment accumulation (years)	Reservoir capacity		Sediment yield for indicated period			Reference
	Original (acre-ft)	Most recent survey (acre-ft)	Total (acre-ft)	Mean annual (acre-ft)	Mean annual (acre-ft/mi^2)	
9	29.05	25.10	3.95	0.439	3.13	U.S. Bureau of Land Management, 1982
41	8.63	6.08	2.55	.062	.24	--Do.--
3	400	382.9	17.1	5.70	1.50	U.S. Soil Conservation Service (written commun., 1983)
44	8.92	7.48	1.44	.033	.07	U.S. Bureau of Land Management, 1982
27	16.10	8.80	7.30	.270	1.18	--Do.--
33	4.70	3.33	1.37	.041	.26	--Do.--
1	--	--	.576	.576	1.92	Western Energy Co., (written commun., 1983)
2	--	--	.563	.281	1.34	--Do.--
33	7.74	3.65	4.09	.123	.68	U.S. Bureau of Land Management, 1982
36	5.92	4.83	1.09	.030	.34	--Do.--
9	72,510	69,439	3,071	327	.188	Dendy and Champion, 1978
37	--	--	1.51	.041	.055	L. M. Shown (U.S. Office of Surface Mining, written commun., 1983)
37	--	--	1.06	.029	.095	--Do.--
39	--	--	2.403	.062	.237	--Do.--
38	--	--	.864	.023	.037	--Do.--
39	--	--	1.67	.043	.04	U.S. Department of the Interior, 1977b
39	--	--	.67	.017	.02	--Do.--

Table 5.--*Summary of reservoir sedimentation surveys*--Continued

Map No. (fig. 1)	Reservoir	Major drainage basin	Subbasin	Location	Drainage area[1] (square miles)	Date of construction or initial survey (month-year)	Date of most recent survey (month-year)
18	F	Hanging Woman Creek.	Trail Creek.	sec. 19, T. 9 S., R. 44 E.	.16	1940	08-76
19	Brown Cattle Co.	Tongue River	Coal Bank Creek.	sec. 33, T. 5 S., R. 42 E.	1.16	1940	1982
20	SP-16	Tongue River	O'Dell Creek.	sec. 36, T. 4 S., R. 43 E.	.384	1943	1979
21	SP-18	Tongue River	O'Dell Creek.	sec. 32, T. 4 S., R. 44 E.	.158	1946	1979
22	SP-21	Tongue River	Cedar Creek.	sec. 16, T. 4 S., R. 44 E.	.547	1954	1979
23	SP-23	Tongue River	King Creek.	sec. 9, T. 4 S., R. 44 E.	.090	1969	1979
24	Bales Ranch (#12).	Otter Creek	Bear Creek.	sec. 12, T. 9 S., R. 45 E.	.222	1966	09-75
25	Bales Ranch (#10).	Otter Creek	Bear Creek.	sec. 10, T. 9 S., R. 45 E.	.426	1952	09-75
26	P1	Otter Creek	Home Creek.	sec. 34, T. 3 S., R. 45 E.	.21	1960	08-74
27	P2	Otter Creek	Home Creek.	sec. 26, T. 3 S., R. 45 E.	.79	1934	08-74
28	P3	Otter Creek	Home Creek.	sec. 25, T. 3 S., R. 45 E.	.23	1934	08-74
29	P4	Otter Creek	Threemile Creek.	sec. 11, T. 4 S., R. 45 E.	.45	1961	08-74
30	A. J.	Pumpkin Creek.	Rough Creek.	sec. 34, T. 4 N., R. 49 E.	.10	1960	07-82
31	Herzog	Yellowstone River.	Dry Creek	sec. 20, T. 8 N., R. 48 E.	6.92	1941	1969
32	Venn	North Sunday Creek.	Owens Coulee.	sec. 13, T. 9 N., R. 45 E.	7.68	1938	1963
33	Scraper	Yellowstone River.	Dixon Creek.	sec. 29, T. 9 N., R. 49 E.	.13	1971	1982
34	Draw	Yellowstone River.	Deep Creek.	sec. 28, T. 9 N., R. 49 E.	.08	1971	07-82
35	Rough Creek.	Powder River	Rough Creek.	sec. 12, T. 9 S., R. 47 E.	.19	1970	09-82

Period of sediment accumulation (years)	Reservoir capacity		Sediment yield for indicated period			Reference
	Original (acre-ft)	Most recent survey (acre-ft)	Total (acre-ft)	Mean annual (acre-ft)	Mean annual (acre-ft/mi^2)	
36	--	--	.53	.015	.09	--Do.--
42	6.26	3.62	2.64	.063	.05	U.S. Bureau of Land Management (written commun., 1983)
36	--	--	4.36	.121	.32	Montco, 1981
33	--	--	.51	.015	.10	--Do.--
25	--	--	3.10	.124	.23	--Do.--
10	--	--	.21	.021	.23	--Do.--
9	--	--	.649	.072	.325	L. M. Shown (U.S. Office of Surface Mining, written commun., 1983)
23	--	--	1.414	.061	.144	--Do.--
14	--	--	.970	.069	.33	U.S. Department of the Interior, 1975
40	--	--	6.64	.166	.21	--Do.--
40	--	--	1.84	.046	.20	--Do.--
13	--	--	2.11	.162	.36	--Do.--
22	3.80	1.25	2.55	.116	1.16	U.S. Bureau of Land Management (written commun., 1983)
28	300	222	78.0	2.79	.403	U.S. Soil Conservation Service (written commun., 1983)
25	280	213.5	66.5	2.66	.346	--Do.--
11	8.53	6.79	1.74	.158	1.22	--Do.--
11	3.18	2.35	.83	.075	.94	--Do.--
12	4.11	3.43	.68	.057	.30	U.S. Bureau of Land Management (written commun., 1983)

Table 5.--*Summary of reservoir sedimentation surveys*--Continued

Map No. (fig. 1)	Reservoir	Major drainage basin	Subbasin	Location	Drainage area[1] (square miles)	Date of construction or initial survey (month-year)	Date of most recent survey (month-year)
36	State	Powder River	Unnamed	sec. 16, T. 8 S., R. 49 E.	.10	1939	07-82
37	Rough	Powder River	Rough Creek.	sec. 17, T. 5 S., R. 50 E.	.45	1963	1981
38	Mackey	Powder River	Horse Creek.	sec. 11, T. 3 S., R. 53 E.	.33	1959	1982
39	Grass	Powder River	Crow Creek.	sec. 32, T. 3 S., R. 55 E.	.56	1965	1982
40	Schaffer	Powder River	Crow Creek.	sec. 2, T. 2 S., R. 53 E.	.09	1964	1982
41	Poecheaie	Powder River	Timber Creek.	sec. 21, T. 3 S., R. 55 E.	.31	1945	1981
42	Broken Stove.	Powder River	Dry Creek	sec. 8, T. 1 S., R. 55 E.	.22	1951	1982
43	Ashby Draw.	Powder River	Spring Creek.	sec. 18, T. 1 S., R. 56 E.	.67	1959	1982
44	MacKenzie	Powder River	Mason Creek.	sec. 30, T. 5 N., R. 53 E.	.08	1951	08-80
45	Subbasin F.	Mizpah Creek	Second Creek.	sec. 22, T. 3 S., R. 49 E.	.39	--	--
46	Woodruff	Powder River	Locate Creek.	sec. 7, T. 7 N., R. 53 E.	.07	1950	08-80
47	Haughian	Yellowstone River.	Crooked Creek.	sec. 2, T. 11 N., R. 49 E.	.09	1953	08-80
48	Keltner	Cherry Creek	Unnamed	sec. 2, T. 13 N., R. 49 E.	.17	1936	07-80
49	Baker	O'Fallon Creek.	Sandstone Creek.	sec. 13, T. 7 N., R. 59 E.	5.01	05-08	07-70
50	Gray	O'Fallon Creek.	Ash Creek	sec. 20, T. 9 N., R. 54 E.	.26	1952	08-80
51	Lark	Yellowstone River.	Unnamed	sec. 15, T. 14 N., R. 55 E.	.29	1968	06-81
52	Bradac	Little Beaver Creek.	Buffalo Creek.	sec. 12, T. 6 N., R. 60 E.	.21	09-58	09-80
53	Sagebrush Pit.	Boxelder Creek.	Whitetail Creek.	sec. 19, T. 5 S., R. 57 E.	.13	1969	1981
54	Whitetail Pit.	Boxelder Creek.	Whitetail Creek.	sec. 14, T. 5 S., R. 57 E.	.16	1968	1981

Period of sediment accumulation (years)	Reservoir capacity Original (acre-ft)	Most recent survey (acre-ft)	Sediment yield for indicated period Total (acre-ft)	Mean annual (acre-ft)	(acre-ft/mi^2)	Reference
43	11.27	8.79	2.48	.058	.58	--Do.--
18	18.56	0	18.56	1.03	2.29	--Do.--
23	3.61	3.44	.17	.007	.02	--Do.--
17	7.20	5.07	2.13	.125	.22	--Do.--
18	3.84	3.71	.13	.007	.08	--Do.--
36	6.55	4.12	2.43	.068	.22	--Do.--
31	8.95	6.86	2.09	.067	.31	--Do.--
23	34.52	29.47	5.05	.220	.33	--Do.--
29	2.90	2.46	.44	.015	.19	U.S. Bureau of Land Management, 1982
--	--	--	--	--	.06	U.S. Department of the Interior, 1982
30	.76	.43	.33	.011	.16	U.S. Bureau of Land Management, 1982
27	8.50	3.58	4.92	.182	2.02	--Do.--
44	2.48	.62	1.86	.042	.25	--Do.--
62	756	235	521	8.36	1.67	Dendy and Champion, 1978
28	5.61	3.33	2.28	.081	.31	U.S. Bureau of Land Management, 1982
13	2.86	2.29	.57	.044	.15	--Do.--
22	1.20	.25	.95	.043	.21	--Do.--
12	2.62	2.38	.24	.020	.15	U.S. Bureau of Land Management (written commun., 1983)
13	2.53	1.72	.81	.062	.39	--Do.--

Table 5.--*Summary of reservoir and sedimentation surveys*--Continued

Map No. (fig. 1)	Reservoir	Major drainage basin	Subbasin	Location	Drainage area[1] (square miles)	Date of construction or initial survey (month-year)	Date of most recent survey (month-year)
55	Humbolt Pit.	Boxelder Creek.	South Creek.	sec. 19, T. 3 S., R. 58 E.	.04	1970	08-82
56	HCC-2 Pit	Boxelder Creek.	Dead Boy Creek.	sec. 26, T. 2 S., R. 58 E.	.30	1956	1982
57	Cline Pit	Boxelder Creek.	Buffalo Creek.	sec. 33, T. 1 S., R. 58 E.	.13	1966	08-82
58	Bullrush Pit.	Boxelder Creek.	Buffalo Creek.	sec. 14, T. 2 S., R. 58 E.	.18	1969	08-82
59	Coyote Pit.	Boxelder Creek.	Buffalo Creek.	sec. 20, T. 2 S., R. 59 E.	.01	1972	1981
60	Softwater Pit.	Boxelder Creek.	Buffalo Creek.	sec. 24, T. 2 S., R. 58 E.	.08	1960	1981
61	Jack Rabbit.	Boxelder Creek.	Buffalo Creek.	sec. 13, T. 2 S., R. 58 E.	1.63	1964	1981
62	Blackfoot Ferret Pit.	Little Missouri River.	Thompson Creek.	sec. 26, T. 9 S., R. 57 E.	.07	1967	1982
63	Red Head Pit.	Little Missouri River.	Willow Creek.	sec. 1, T. 8 S., R. 57 E.	.33	1967	1982
64	North End	Little Missouri River.	Cottonwood Creek.	sec. 27, T. 6 S., R. 58 E.	.04	1963	1982
65	Lone Tree Pit.	Little Missouri River.	Unnamed	sec. 7, T. 6 S., R. 61 E.	.29	1973	1981
66	Short Day	Little Missouri River.	Elkhorn Creek.	sec. 25, T. 7 S., R. 62 E.	.14	1958	1982
67	Middle	Belle Fourche River.	Crow Creek	sec. 34, T. 9 S., R. 61 E.	.03	1955	1982
68	Dean Pit	Belle Fourche River.	Indian Creek.	sec. 10, T. 9 S., R. 62 E.	.08	1971	1982

[1] Drainage area assumed to be contributing part of total upstream area.
[2] Sediment yield represents post-mining disturbed land.
[3] Date of construction estimated at about 1943 (L. M. Shown, U.S. Office of Surface Mining, oral commun., 1983).

Period of sediment accumulation (years)	Reservoir capacity		Sediment yield for indicated period			Reference
	Original (acre-ft)	Most recent survey (acre-ft)	Total (acre-ft)	Mean annual (acre-ft)	Mean annual (acre-ft/mi^2)	
12	4.89	1.99	2.90	.242	6.04	--Do.--
26	5.72	2.21	3.51	.135	.45	--Do.--
16	3.45	.98	2.47	.154	1.19	--Do.--
13	3.26	1.01	2.25	.173	.96	--Do.--
9	3.60	2.40	1.20	.133	13.33	--Do.--
21	4.01	1.68	2.33	.111	1.39	--Do.--
17	58.70	45.67	13.03	.766	.47	--Do.--
15	5.99	2.56	3.43	.229	3.27	--Do.--
15	3.82	2.78	1.04	.069	.21	--Do.--
19	10.05	7.22	2.83	.149	3.72	--Do.--
8	1.64	.13	1.51	.189	.65	--Do.--
24	4.73	2.52	2.21	.092	.66	--Do.--
27	9.66	7.71	1.95	.072	2.41	--Do.--
11	6.53	5.62	.91	.083	1.03	--Do.--

Table 6.--*Summary of suspended-sediment yields at stream-sampling sites*

[acre-ft, acre-feet; acre-ft/mi^2, acre feet per square mile. Significant figures reported in table are same as given in reference]

Map No. (fig. 1)	Stream site	Location	Drainage area (square miles)	Period of sediment record (years)	Sampling frequency [1]	Mean annual flow [2] (acre-ft)	Mean annual suspended sediment load [3] (tons)	Mean annual suspended sediment yield (acre-ft/mi^2)	Reference
				Missouri River basin					
69	Nelson Creek nr Van Norman.	sec. 36, T. 21 N., R. 43 E.	100	4	Monthly	2,510	4,680	0.036	Lambing, 1983
70	Prairie Elk Creek nr Oswego.	sec. 14, T. 26 N., R. 45 E.	352	4	Monthly	20,220	68,500	.150	--Do.--
71	Redwater River at Circle.	sec. 11, T. 19 N., R. 48 E.	547	7	Monthly	6,420	967	.002	--Do.--
72	Redwater River nr Vida.	sec. 24, T. 25 N., R. 50 E.	1,974	6	Monthly	34,700	10,600	.004	--Do.--
				Yellowstone River basin					
73	Sarpy Creek nr Hysham.	sec. 30, T. 6 N., R. 37 E.	453	5	Monthly	8,050	1,700	.003	Litke, 1983
74	Armells Creek nr Forsyth.	sec. 26, T. 6 N., R. 39 E.	370	5	Monthly	7,240	3,150	.007	--Do.--
75	Rosebud Creek nr Colstrip.	sec. 8, T. 1 S., R. 42 E.	799	5	Monthly	47,240	22,000	.02	--Do.--
76	Rosebud Creek at mouth, nr Rosebud.	sec. 21, T. 6 N., R. 42 E.	1,302	5	Monthly	54,770	48,000	.03	--Do.--
77	Squirrel Creek nr Decker.	sec. 14, T. 9 S., R. 39 E.	33.6	4	Monthly	4,050	1,190	.03	--Do.--
78	Tongue River at State line, nr Decker.	sec. 33, T. 9 S., R. 40 E.	1,480	--	--	357,000	363,000	[4].16	U.S. Department of the Interior and Montana Department of State Lands, 1977.
79	Tongue River at Tongue River Dam, nr Decker.	sec. 12, T. 8 S., R. 40 E.	1,770	4	Monthly	339,100	10,300	.004	Litke, 1983
80	Hanging Woman Creek nr Birney.	sec. 19, T. 6 S., R. 43 E.	470	5	Monthly	4,830	1,130	.002	--Do.--

Table 6.--*Summary of suspended-sediment yields at stream-sampling sites*--Continued

Map No. (fig. 1)	Stream site	Location	Drainage area (square miles)	Period of sediment record (years)	Sampling frequency[1]	Mean annual flow[2] (acre-ft)	Mean annual suspended sediment load[3] (tons)	Mean annual suspended sediment yield (acre-ft/mi^2)	Reference
		Yellowstone River basin--Continued							
81	Otter Creek at Ashland.	sec. 11, T. 3 S., R. 44 E.	707	5	Monthly	6,900	770	.001	--Do.--
82	Tongue River bl Brandenberg bridge, nr Ashland.	sec. 6, T. 1 N., R. 45 E.	4,062	6	Daily	417,300	194,000	.04	--Do.--
83	Pumpkin Creek nr Miles City.	sec. 35, T. 6 N., R. 48 E.	697	4	Monthly	17,120	45,000	.05	--Do.--
84	Tongue River at Miles City.	sec. 23, T. 7 N., R. 47 E.	5,379	7	Monthly (5 years) Daily (2 years)	328,900	634,000	.09	--Do.--
85	Yellowstone River at Miles City.	sec. 28, T. 8 N., R. 47 E.	48,253	3	Daily	8,920,000	16,580,000	.26	Koch and others, 1977
86	Powder River at Moorhead.	sec. 8, T. 9 S., R. 48 E.	8,088	5	Daily	338,300	5,230,000	.49	Litke, 1983
87	Powder River at Broadus.	sec. 3, T. 5 S., R. 51 E.	8,748	5	Daily	371,700	5,470,000	.48	--Do.--
88	Mizpah Creek nr Mizpah.	sec. 24, T. 6 N., R. 51 E.	797	4	Monthly	17,320	60,800	.06	--Do.--
89	Powder River nr Locate.	sec. 14, T. 8 N., R. 51 E.	13,189	9	Daily	457,900	4,240,000	.25	--Do.--
90	Burns Creek nr Savage.	sec. 27, T. 19 N., R. 57 E.	233	4	Monthly	7,960	1,520	.005	Lambing, 1983
91	Yellowstone River nr Sidney.	sec. 9, T. 22 N., R. 59 E.	69,103	37	Daily	9,194,000	25,051,000	.20	Koch and others, 1977

[1] Sediment yields determined from monthly samples were calculated by the sediment rating-flow duration method; sediment yields determined from daily samples were calculated directly.

[2] Mean annual flow may not correspond exactly to period of sediment record.

[3] Density of sediment assumed to be 60 pounds per cubic foot for all sites except Tongue River at State line, which is 70 pounds per cubic foot.

[4] Sediment yield estimated by weighting Tongue River Reservoir sedimentation.

Table 7.--*Summary of sediment yields determined by indirect estimation*

[Method of estimation: USLE, Universal Soil Loss Equation; PSIAC, Pacific Southwest Inter-Agency Committee. Significant figures reported in table are same as given in reference.]

Map No. (fig. 1)	Study basin [1]	Location of study basin outlet	Drainage area (mi^2)	Mean annual gross erosion (acre-ft/mi^2)	Sediment-delivery ratio	Mean annual sediment yield (acre-ft/mi^2)	Method of estimation	Reference
				Yellowstone River basin				
				Tongue River subbasin				
92	Squirrel Creek tributary (a).	sec. 14, T. 9 S., R. 39 E.	0.66	0.216	0.32	0.069	Regression	Consolidation Coal Company, 1981
93	Squirrel Creek tributary (b).	sec. 14, T. 9 S., R. 39 E.	.19	.233	.39	.091	--do.--	--Do.--
94	Squirrel Creek tributary (c).	sec. 24, T. 9 S., R. 39 E.	1.29	.039	.28	.011	--do.--	--Do.--
95	Squirrel Creek tributary (d).	sec. 24, T. 9 S., R. 39 E.	.30	.954	.37	.353	--do.--	--Do.--
96	Squirrel Creek tributary (e).	sec. 30, T. 9 S., R. 40 E.	.18	.503	.39	.196	--do.--	--Do.--
97	Pond Creek	sec. 16, T. 9 S., R. 40 E.	6.1	1.65	.27	.45	USLE	U.S. Department of the Interior and Montana Department of State Lands, 1977
98	Coal Creek	sec. 13, T. 9 S., R. 40 E.	2.9	1.65	.31	.51	--do.--	--Do.--
99	Middle Creek	sec. 12, T. 9 S., R. 40 E.	6.3	1.65	.29	.48	--do.--	--Do.--
100	Deer Creek	sec. 1, T. 9 S., R. 40 E.	53.3	1.65	.17	.28	--do.--	--Do.--
101	Pearson Creek	sec. 3, T. 9 S., R. 40 E.	8.5	1.65	.23	.38	--do.--	--Do.--
102	Spring Creek	sec. 33, T. 8 S., R. 40 E.	36.9	1.65	.22	.36	--do.--	--Do.--
103	East Trail Creek tributary.[2,3]	sec. 12, T. 9 S., R. 43 E.	.81	.58	.08	[3] .04	--do.--	Hadley and others, 1981
	East Trail Creek tributary.[2,4]	sec. 12, T, 9 S., R. 43 E.	.81	.42	.08	[4] .03	--do.--	--Do.--
	East Trail Creek tributary (B).[2]	sec. 12, T. 9 S., R. 43 E.	.81	.22-.33	.2	[3] .04-.07	PSIAC	U.S. Department of the Interior, 1977b
104	East Trail Creek (A).	sec. 11, T. 9 S., R. 43 E.	33.5	.22-.31	.1	.02-.03	--do.--	--Do.--
105	Stagmire Draw (D)	sec. 8, T. 9 S., R. 44 E.	7.63	.20-.26	.1	.02-.03	--do.--	--Do.--
106	Bear Creek tributary (C).	sec. 11, T. 9 S., R. 45 E.	1.3	--	--	.05-.08	--do.--	U.S. Department of the Interior, 1977a
107	Bear Creek tributary (E).	sec. 11, T. 9 S., R. 45 E.	.2	--	--	.31-.47	--do.--	--Do.--

Table 7.--*Summary of sediment yields determined by indirect estimation*--Continued

Map No. (fig. 1)	Study basin[1]	Location of study basin outlet	Drainage area (mi^2)	Mean annual gross erosion (acre-ft/mi^2)	Sediment-delivery ratio	Mean annual sediment yield (acre-ft/mi^2)	Method of estimation	Reference
			Yellowstone River basin--Continued					
			Tongue River basin--Continued					
108	Bales Creek (A)	sec. 11, T. 9 S., R. 45 E.	3.3	--	--	.10-.30	--do.--	--Do.--
109	Bear Creek (B)	sec. 11, T. 9 S., R. 45 E.	5.0	--	--	.10-.30	--do.--	--Do.--
110	Bear Creek tributary (D).	sec. 2, T. 9 S., R. 45 E.	.7	--	--	.17-.27	--do.--	--Do.--
111	Bear Creek tributary (F).	sec. 3, T. 9 S., R. 45 E.	.4	--	--	.21-.36	--do.--	--Do.--
112	Bear Creek tributary (G).	sec. 3, T. 9 S., R. 45 E.	.4	--	--	.21-.38	PSIAC	U.S. Department of the Interior, 1977a
113	Bear Creek tributary (H).	sec. 34, T. 8 S., R. 45 E.	.9	--	--	.26-.38	--do.--	--Do.--
114	Bear Creek (I)	sec. 34, T. 8 S., R. 45 E.	1.6	--	--	.04-.07	--do.--	--Do.--
115	Vance Creek tributary (L).	sec. 4, T. 9 S., R. 45 E.	.4	--	--	.14-.23	--do.--	--Do.--
116	Vance Creek tributary (K).	sec. 32, T. 8 S., R. 45 E.	4.6	--	--	.10-.30	--do.--	--Do.--
117	Vance Creek (J)	sec. 33, T. 8 S., R. 45 E.	8.2	--	--	.10-.30	--do.--	--Do.--
118	Threemile Creek tributary (F).	sec. 2, T. 4 S., R. 45 E.	1.01	.57	.5	.3	--do.--	U.S. Department of the Interior, 1975
119	Threemile Creek tributary (D).	sec. 3, T. 4 S., R. 45 E.	.45	.39	.75	.3	--do.--	--Do.--
120	Home Creek tributary (C).	sec. 34, T. 3 S., R. 45 E.	.54	.33	.65	.2	--do.--	--Do.--
121	Home Creek tributary (B).	sec. 27, T. 3 S., R. 45 E.	.27	.21	.5	.1	--do.--	--Do.--

[1] Letter accompanying study basin name refers to designation given in reference.

[2] Sediment-yields for same site on East Trail Creek tributary estimated in two separate studies.

[3] Pre-mining estimate of sediment yield.

[4] Post-reclamation estimate of sediment yield.

Table 8.--*Basin characteristics of reservoirs with drainage areas less than 2 square miles*

[GEO: Tft, Tongue River Member of Fort Union Formation; Tfl, Lebo Shale Member of Fort Union Formation; Tftu, Tullock Member of Fort Union Formation; Kh, Hell Creek Formation; Kf, Fox Hills Sandstone; Kb, Bearpaw Shale; Kcl, Claggett Formation; Kp, Pierre Shale; Kn, Niobrara Formation; Kc, Carlile Shale; Kbf, Belle Fourche Shale. SMR: AR, aridic; U, ustic; AQ, aquic. VS: See table 9]

Map No. (fig. 1)	Reservoir	Dependent variable	Independent variables										Physical regimes		
		SEDYLD	*DA*	*DD*	*RL*	*WL*	*MR*	*FC*	*MAP*	*MAF*	Q_2	Q_5	*GEO*	*SMR*	*VS*
1	Shaw	3.13	0.14	10.4	0.046	0.571	0.816	0	14.0	0.043	42.2	170	Kb	AR-U-AQ	18
2	Brackett	.24	.26	5.90	.036	.405	.937	0	12.0	.027	34.5	137	Tfl	AR	14
4	Chickie	.07	.49	3.25	.040	.345	.832	0	14.0	.041	17.6	68.1	Tft	AR	14
5	Dons	1.18	.23	13.9	.041	.959	.612	0	12.8	.030	34.3	136	Kcl	AR	20
6	Cornwell	.26	.16	5.58	.045	.881	.810	0	12.0	.025	71.8	287	Kb	AR-U-AQ	18
9	Barley	.67	.18	4.00	.044	.458	.750	0	12.0	.028	49.8	199	Tfl	AR	16
10	Lockie	.34	.09	8.41	.040	.375	.667	0	12.0	.022	58.2	240	Tftu	AR	16
12	Prairie Dog NW.	.06	.74	6.34	.069	.911	1.20	1.4	16.0	.054	26.2	72.2	Tft	U	25
13	Prairie Dog SE.	.10	.30	5.90	.062	1.24	.918	2.3	16.0	.053	35.3	97.7	Tft	U	25
14	Corral	.24	.26	13.8	.119	.582	.926	41.5	15.0	.019	9.19	25.2	Tft	AR	24
15	Jeffreys Prong.	.04	.62	8.53	.078	.636	.980	41.0	14.0	.016	6.50	17.6	Tft	AR	24
16	C	.04	.96	10.1	.040	.621	1.04	16.5	14.0	.023	23.6	64.2	Tft	AR	14
17	E	.02	.87	8.39	.053	.565	1.02	12.6	14.0	.025	28.7	78.2	Tft	AR	14
18	F	.09	.16	13.1	.056	.491	.947	16.2	14.0	.025	49.7	138	Tft	AR	14
19	Brown Cattle Co.	.05	1.16	9.65	.097	.433	1.05	16.4	14.0	.022	9.74	26.4	Tft	AR	24
20	SP-16	.32	.38	9.64	.078	.529	1.04	2.6	14.0	.037	44.5	123	Tft	AR	18
21	SP-18	.10	.16	7.34	.102	.333	.928	0	14.0	.044	96.2	269	Tft	AR	18
22	SP-21	.23	.55	8.34	.057	.339	1.05	4.2	13.4	.029	37.7	103	Tft	AR	18
23	SP-23	.23	.09	9.56	.037	1.14	1.07	12.2	15.1	.033	50.9	142	Tft	AR	18
24	Bales Ranch (#12).	.32	.22	7.66	.054	.590	.902	0	19.6	.100	112	311	Tft	AR	14
25	Bales Ranch (#10).	.14	.43	8.68	.043	.458	.906	1.6	16.1	.053	73.9	204	Tft	AR	14
26	P1	.33	.21	9.95	.038	.373	.880	12.4	14.8	.029	51.9	143	Tft	AR	25
27	P2	.21	.79	10.5	.033	.444	.894	3.7	14.0	.034	48.7	134	Tft	AR	25
28	P3	.20	.23	5.87	.053	.796	.907	10.0	14.0	.026	55.7	154	Tft	AR	25
29	P4	.36	.45	12.6	.042	.427	1.13	1.0	15.4	.049	76.2	210	Tft	AR	18
30	A. J.	1.16	.10	11.9	.050	.316	.737	0	13.5	.040	96.9	272	Tfl	AR	14
33	Scraper	1.22	.13	8.92	.042	.444	.759	0	15.0	.046	105	292	Tfl	AR	21
34	Draw	.94	.08	9.62	.051	.442	.767	5.0	15.0	.038	85.6	240	Tfl	AR	21
35	Rough Creek	.30	.19	12.1	.141	.418	.925	41.5	14.9	.021	24.0	66.0	Tft	AR	24
36	State	.58	.10	13.1	.065	.365	.538	3.0	13.0	.030	89.9	252	Tft	AR	24

Table 8.--*Basin characteristics of reservoirs with drainage areas less than 2 square miles*--Continued

Map No. (fig. 1)	Reservoir	Dependent variable	Independent variables										Physical regimes		
		SEDYLD	*DA*	*DD*	*RL*	*WL*	*MR*	*FC*	*MAP*	*MAF*	Q_2	Q_5	*GEO*	*SMR*	*VS*
37	Rough	2.29	.45	12.0	.090	.490	.750	13.3	14.3	.027	23.1	63.3	Tft	AR	18
38	Mackey	.02	.33	8.48	.034	.290	.832	0	14.2	.042	47.6	132	Tftu	AR	18
39	Grass	.22	.56	5.14	.024	.464	.936	0	14.3	.043	47.9	132	Kf	AR-U-AQ	18
40	Schaffer	.08	.09	8.89	.035	.367	.857	0	15.2	.056	101	284	Khc	AR	14
41	Poecheaie	.22	.31	4.23	.036	.424	.753	0	14.0	.042	61.0	169	Kfh	AR-U-AQ	18
42	Broken Stove	.31	.22	7.59	.054	.443	.857	0	14.0	.041	77.8	216	Khc	AR	14
43	Ashby Draw	.33	.67	8.32	.034	.500	.983	1.0	17.3	.067	40.4	111	Khc	AR	14
44	MacKenzie	.19	.08	13.9	.050	.246	.877	0	14.0	.038	126	355	Khc	AR-U-AQ	14
45	Subbasin F	.06	.39	5.56	.030	.585	.866	0	15.0	.049	66.7	184	Tft	AR	14
46	Woodruff	.16	.07	3.04	.049	1.12	.440	16.4	14.0	.029	95.4	268	Tft	AR	24
47	Haughian	2.02	.09	12.1	.037	.413	.739	0	12.0	.022	107	436	Tfl	AR	14
48	Keltner	.25	.17	12.7	.046	.282	.987	0	13.0	.035	39.9	160	Tft	AR	16
50	Gray	.31	.26	8.99	.032	.529	.871	0	13.2	.035	78.7	219	Tft	AR	14
51	Lark	.15	.29	9.59	.048	.330	.862	2.1	14.0	.038	62.4	173	Kp	AR-U-AQ	17
52	Bradac	.21	.21	11.2	.022	.784	.765	0	14.7	.048	71.8	200	Kp	AR-U-AQ	20
53	Sagebrush Pit	.15	.13	7.23	.029	.644	1.02	0	14.1	.038	105	292	Kp	AR-U-AQ	18
54	Whitetail Pit	.39	.16	3.88	.027	.673	.694	0	13.8	.038	88.1	246	Kp	AR-U-AQ	18
55	Humbolt Pit	6.04	.04	17.1	.065	.773	.773	0	14.8	.050	158	450	Kp	AR-U-AQ	18
56	HCC-2 Pit	.45	.30	6.73	.013	.481	.873	0	13.9	.040	61.7	171	Kp	AR-U-AQ	18
57	Cline Pit	1.19	.13	11.4	.025	.609	.978	0	14.6	.046	86.9	243	Kp	AR-U-AQ	18
58	Bullrush Pit	.96	.18	10.8	.017	.561	1.05	0	14.4	.044	76.1	212	Kp	AR-U-AQ	18
59	Coyote Pit	13.3	.01	13.0	.047	.375	.688	0	16.0	.100	249	715	Kp	AR-U-AQ	18
60	Softwater Pit.	1.39	.08	12.0	.018	.100	.833	0	14.0	.038	106	299	Kp	AR-U-AQ	18
61	Jack Rabbit	.47	1.63	10.9	.018	.638	1.10	0	14.3	.042	30.9	84.0	Kp	AR-U-AQ	18
62	Blackfoot Ferret Pit.	3.27	.07	15.8	.033	.618	.882	0	15.0	.057	123	347	Kbf	AR-U-AQ	18
63	Red Head Pit	.21	.33	4.06	.021	.459	.859	0	15.0	.048	71.2	198	Kc	AR-U-AQ	20
64	North End	3.72	.04	16.2	.053	.640	.600	0	14.1	.050	169	480	Kp	AR-U-AQ	18
65	Lone Tree Pit	.65	.29	8.72	.060	.316	.926	0	14.7	.048	69.0	191	Kp	AR-U-AQ	18
66	Short Day	.66	.14	2.07	.006	.383	.217	0	14.0	.043	92.9	259	Kp	AR-U-AQ	18
67	Middle	2.41	.03	9.33	.055	.842	.421	0	14.0	.033	159	450	Kn	AR-U-AQ	18
68	Dean Pit	1.03	.08	10.0	.032	.354	.792	0	15.3	.050	117	329	Kp	AR-U-AQ	18

Table 9.--*Description of vegetation/soil complexes in eastern Montana*[1]

[", inch; P. Z., precipitation zone; %, percent]

Map unit (fig. 3)	Vegetation/soil description	Vegetation/soil complex
1	Silty Range Site, 10-14" P. Z. (Includes thin breaks too small or irregular to delineate) Needleandthread, western and thickspike wheatgrass, green needlegrass, little bluestem, prairie junegrass, porcupinegrass, blue grama, native legumes, silver sagebrush, western snowberry, winterfat	A
2	Silty-Clayey Range Site Complex, 10-14" P. Z. Silty: Same as Site No. 1 Clayey: Western and thickspike wheatgrass, green needlegrass, little bluestem, prairie junegrass, plains reedgrass, biscuitroot, milkvetches, American vetch, silver sagebrush, winterfat	--Do.--
14	Silty Range Site, 10-14" P. Z. (Includes thin breaks too small or irregular to delineate) Western and thickspike wheatgrass, little bluestem, needleandthread, green needlegrass, bluebunch wheatgrass, big bluestem, prairie junegrass, threadleaf sedge, native legumes, silver sagebrush, skunkbush, sumac, winterfat, blue grama, western snowberry	--Do.--
15	Silty Range Site, 15-19" P. Z. Western and thickspike wheatgrass, green needlegrass, little bluestem, big bluestem, bluebunch wheatgrass, Idaho fescue, sideoats grama, native legumes, needleandthread, prairie junegrass, silver sagebrush	--Do.--
16	Silty-Clayey Range Site Complex, 10-14" P. Z. (Includes thin breaks too small or irregular to delineate) Silty: Same as Site No. 14 Clayey: Same as Site No. 18	--Do.--
17	Silty-Clayey Range Site Complex, 15-19" P. Z. Silty: Same as Site No. 15 Clayey: Same as Site No. 19	--Do.--
21	Sands and Sandy Range Site Association, 10-14" P. Z. Sands: Prairie sandreed, needleandthread, sand bluestem, Indian rice-grass, little bluestem, sun sedge, native legumes, skunkbush sumac, yucca Sandy: Needleandthread, prairie sandreed, threadleaf sedge, little bluestem, sideoats grama, big bluestem, native legumes, blue grama, skunkbush sumac, rose	A
18	Clayey and Shallow Clay Range Site Association, 10-14" P. Z. Western and thickspike wheatgrass, green needlegrass, little bluestem, bluebunch wheatgrass, prairie junegrass, native legumes, big sagebrush, Nuttall saltbush, winterfat	B

Table 9.--*Description of vegetation/soil complexes in eastern Montana*[1] --Continued

Map unit (fig. 3)	Vegetation/soil description	Vegetation/soil complex
19	Clayey and Shallow Clay Range Site Association, 15-19" P. Z. Green needlegrass, western and thickspike wheatgrass, bluebunch wheatgrass, basin wildrye, big bluestem, little bluestem, Idaho fescue, prairie junegrass, prairie sandreed, native legumes, big sagebrush, Nuttall saltbush, winterfat	--Do.--
20	Dense Clay-Clayey-Saline Upland Range Site Complex, 10-14" P. Z. Dense Clay: Western and thickspike wheatgrass, green needlegrass, basin wildrye, big sagebrush, Nuttall saltbush, greasewood, prairie junegrass Clayey: Same as Site No. 18 Saline Upland: Alkali sacaton, western and thickspike wheatgrass, greasewood, basin wildrye, Nuttall saltbush, inland saltgrass, bottlebrush squirreltail, Sandberg bluegrass	--Do.--
22	Riverbreaks, 10-14" P. Z. Ponderosa pine, Rocky Mountain juniper, western and thickspike wheatgrass, bluebunch wheatgrass, green needlegrass, prairie sandreed, little bluestem, greasewood, big sagebrush, needleandthread, Nuttall saltbush, basin wildrye, native legumes, shadscale saltbush, creeping juniper	--Do.--
23	Badlands, 10-14" P. Z. Western thickspike wheatgrass, green needlegrass, little bluestem, bluebunch wheatgrass, prairie sandreed, alkali sacaton, prairie junegrass, Nuttall saltbush, big sagebrush, American vetch, plains muhly, sideoats grama, greasewood, juniper	--Do.--
24	Forest-Grassland Complex, 12-14" P. Z. on Very Shallow to Deep Soils with a Frigid Temperature Regime and Light Brown, Loamy Surfaces on Rolling to Hilly Terrain Forest: (50%) Ponderosa pine, Rocky Mountain juniper, little bluestem, bluebunch wheatgrass, sideoats grama, skunkbush sumac, western wheatgrass, native legumes Grassland: (50%) Little bluestem, needleandthread, western wheatgrass, green needlegrass, bluebunch wheatgrass, prairie sandreed, big bluestem, native legumes, skunkbush sumac, yucca, prairie junegrass, blue grama	C
25	Forest-Grassland Complex, 15-19" P. Z., on Very Shallow to Deep Soils with a Frigid Temperature Regime and Light Brown, Loamy Surfaces on Undulating to Hilly Terrain Forest: (60%) Ponderosa pine, bluebunch wheatgrass, Idaho fescue, little bluestem, sideoats grama, snowberry, native legumes, arrowleaf balsamroot, green needlegrass, common chokecherry, saskatoon serviceberry Grassland: (40%) Big bluestem, bluebunch wheatgrass, western wheatgrass, green needlegrass, needleandthread, prairie junegrass, basin wildrye, lupine, snowberry, saskatoon serviceberry, common chokecherry	--Do.--
26	Ponderosa Pine Forests on Moderately Deep to Deep Soils with a Frigid Temperature Regime and Light Brown to Brown Surfaces on Undulating to Steep Terrain, 15-19" P. Z. Typical overstory composition is: Ponderosa Pine 100%	--Do.--

[1] From Ross and Hunter (1976).