Assessing potential impacts of logging and road construction on the soil and water resources in a semi-primitive area
by Ronald Jay Aasheim

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in i Soil Science
Montana State University

Abstract:

Knowledge of intended plans for development of Big Sky, Inc., in the Gallatin Canyon, prompted researchers at Montana State University to apply for, and receive, a National Science Foundation grant to study the Impacts of a Large Recreation Development on a Semi-Primitive Area.

This thesis is part of the larger University study.

Potential impacts of logging and road construction on the soil and water resources in the Porcupine drainage were assessed. Completion of a soil survey, slope map, and location of sediment source areas was the field work that aided most in the assessment of the potential impacts. A literature review was critical in making final conclusions.

It was assumed that only 15 percent of the drainage would be allowed to be disturbed by logging activity at any one time, and that logging operations would be closely supervised.

It was estimated that in the undisturbed condition (as existed at the time of study) that 12.75 tons of sediment would enter the Gallatin River via Porcupine Creek on an average day. Streambank erosion and a few small areas of land instability contributed the greatest share of this. Following logging, it was predicted that 18.8 tons of sediment would enter the Gallatin River via Porcupine Creek on an average day (a 47% increase). The greatest part of this would be the result of road construction.

On-site water yield increases, as a result of logging, were predicted to be less than one inch (1" depth over the entire area of the drainage). Stream temperature increases less than 4°F were predicted if buffer strips were maintained.

Nutrient reserves of the drainage were not predicted to be greatly affected by the removal of timber. A slight increase in stream fertility would result from the logging.

Effects of slash burning were predicted to be small if less than 15 percent of a burn was allowed to burn intensely enough to be classified as a severe burn.

If more than 15 percent of the drainage were allowed to be disturbed by logging operations at any one time, greater impacts would be expected. Land instability would be the first major problem and large increases in sediment yield would result.

No attempt was made to predict the effect that logging activity would have on the elk herd of the drainage. No attempt was made to determine the economic feasibility of logging under strict control.

The effects of changes in sediment yield, stream temperature, stream flow, and stream and soil fertility on the total environment were not predicted.

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ASSESSING POTENTIAL IMPACTS OF LOGGING AND ROAD CONSTRUCTION ON THE SOIL AND WATER RESOURCES IN A SEMI-PRIMITIVE AREA

by

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A thesis submitted to the Graduate Faculty in partial
fulfillment of the requirements for the degree

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in

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INTRODUCTION

Development in the Gallatin

In the winter of 1969-70 it was learned that a large recreation and real estate development, Big Sky, Incorporated, of Montana, was going to be developed on the West Fork of the Gallatin River approximately 45 miles south of Bozeman, Montana. Immediate interest in the magnitude and possible financial benefits to the Gallatin area was followed by a concern for the possible effect the development might have on the relatively pristine environment that would surround Big Sky, Inc. Questions were also raised as to the possible effects on socio-economic characteristics of the area.

It was feared that possibly Big Sky might lead to eventual environmental degradation of the entire Gallatin Canyon if accompanied by uncontrolled and unplanned development.

The Spanish Peaks Wilderness borders the West Fork and concern for the possible destruction of the wilderness resource was voiced.

Selling and exchanging of private land had started and it appeared that with the complex ownership pattern in the Gallatin that planning and proper development might be nearly impossible.

Fig. 1. View of Porcupine Drainage Looking West from Second Creek. Lone Mountain in the Background.

Many valuable resources such as timber and wildlife exist in the Canyon and many felt the proper management of these and other natural resources might be jeopardized.

Others feared the loss of use of parts of the Gallatin for the diversified recreation that the Canyon supports.

The NSF Grant and Study

Researchers at Montana State University, in various disciplines, decided that the Big Sky development and the possible effects it might have on the Gallatin Canyon warranted detailed study. A proposal for a study, The Impact of a Large Recreational Development, (Big Sky, Inc.), on a Semi-Primitive Environment, was prepared and submitted to the National Science Foundation for consideration. In June of 1970 the study was approved and a grant awarded to Montana State University through its Center for Environmental Studies. It is through this grant that this thesis study was funded.

Many disciplines and departments of Montana State University are involved in this study; alphabetically they are: Agricultural Engineering, Archaeology, Architecture, Bioclimatology, Botany, Economics, Education, Entomology, Geology, History, Hydrology, Management Engineering, Microbiology, Plant Pathology, Recreation Area Management, Sociology, Statistics, Soils, Zoology (fish), and Zoology (large mammals).

The Porcupine Study

This research focuses on a tributary to the Gallatin, Porcupine drainage; much of the research and information does apply to other areas of the Gallatin and elsewhere. The Porcupine watershed was chosen for many reasons. Being located only three miles from Big Sky, Inc., it appeared to be an area where future development might take place. It was a watershed that was nearly completely primitive and accordingly a good spot to study the environment before any type of development had taken place. An elk herd of national prominence uses the area as winter range. Beautiful and diverse natural scenery dominates the area and diversified outdoor recreation is available. A timber resource of significant value exists and a checkerboard pattern of land ownership complicates management of the area.

Other factors lend interest to the area. Burlington Northern Railroad, a land owner in the drainage, has a timber contract with Yellowstone Pine of Belgrade, Montana and Yellowstone Pine has requested access to the area and timber.

The Forest Service decided a complete inventory of resources and existing conditions was warranted before deciding upon a management alternative. The University team working in the area was fortunate to participate in this Forest Service study. It was an interesting addition to the larger NSF study.

Scope of the Porcupine Study

Study in the Porcupine drainage commenced in the spring of 1972. Montana State University students were to study primarily geology and soils as they related to possible environmental problems of the area. Development and non-development land use alternatives would be considered. An attempt was made to apply findings in the Porcupine area to other areas of the Gallatin Canyon, and the NSF study in its entirety.

Objectives of This Thesis

The objectives of this study are: to map the soils of the Porcupine Creek and relate this resource to possible environmental problems of the area (sediment production and other problems associated with logging operations); to assess the environmental impact of logging operations upon a semi-primitive environment.

Specifically, research reported here includes analysis of the effects of logging operations on the environment of the drainage; completeion of a soil survey of the Porcupine area and production of a map of the soils of the area; laboratory analyses of the soils; detailed soil profile descriptions of the soils; soil limitation ratings of the area for roads; K-factor or relative soil erodibility predictions; location of sediment source areas; prediction of sediment yield under alternative land uses; completion of a detailed slope map of the drainage; predicting Porcupine Creek discharge and sediment as a percent of the total Gallatin River, and an attempt to predict total sediment load of a stream from discharge.

Location and Description

The Porcupine drainage is located approximately 45 miles south of Bozeman, Montana (Fig. 2). The north boundary is the main ridge between Porcupine Creek and Levinski, Hidden, and Portal Creeks; the east boundary is the main Gallatin Range divide between the Gallatin and Yellowstone Rivers; the south boundary is the main ridge between Porcupine Creek and Buffalo Horn, Elkhorn, and Twin Cabin Creeks; the west boundary is the Gallatin River. Elevation ranges from approximately 6,100 feet at the mouth of Porcupine Creek to approximately 10,000 feet on Eaglehead Mountain. The drainage includes 170,240 acres or 26.6 square miles. Ownership is characterized by a checkerboard pattern of Burlington Northern Railroad, State, and Federal land. (Fig. 3.)

Climate

The climate of the Porcupine area is typical of a mountainous drainage in the Northern Rocky Mountains. The freeze-free season is 50 days or shorter (14). Average annual temperature is approximately 37°F (72). Summer temperatures rarely exceed 90°F and during the

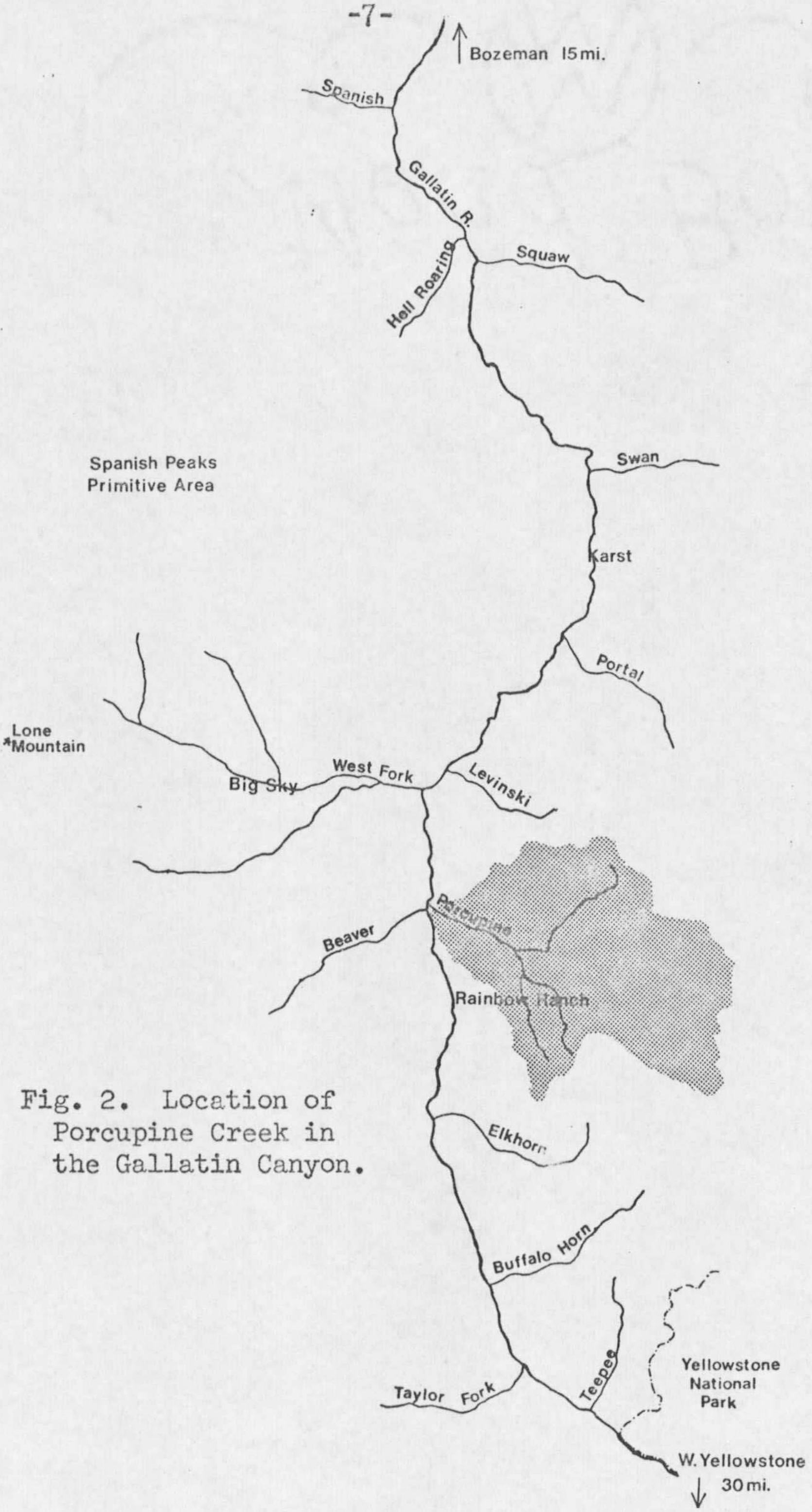

Fig. 2. Location of Porcupine Creek in the Gallatin Canyon.

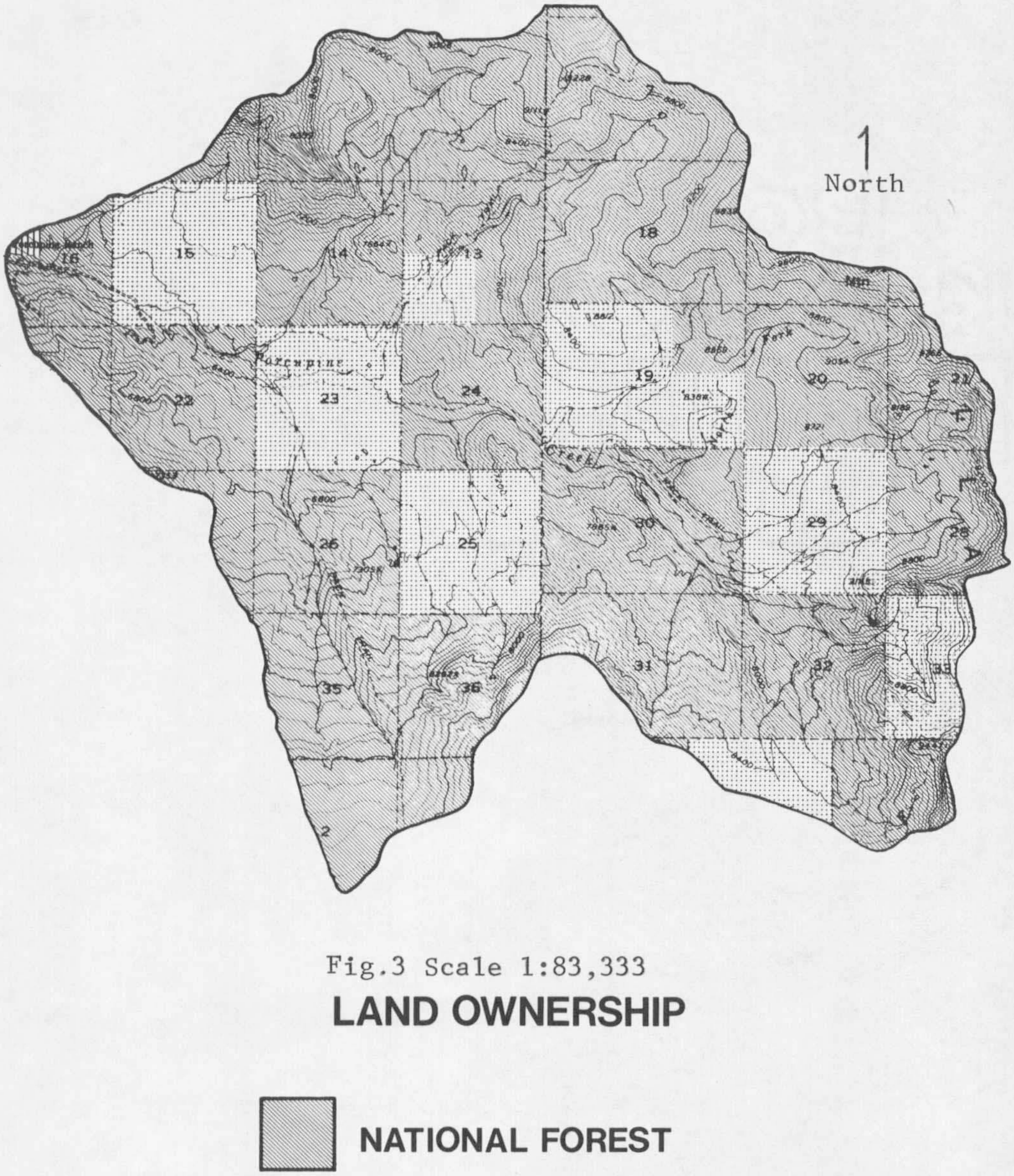

Fig.3 Scale 1:83,333

LAND OWNERSHIP

▨ **NATIONAL FOREST**

░ **BURLINGTON NORTHERN**

▥ **FISH AND GAME**

winter months subzero temperatures are not uncommon (72). According to climatological data supplied by the U.S. Dept. of Commerce (72), between 19 and 22 inches of precipitation falls annually at the mouth of Porcupine Creek. Up to 50 inches have been recorded above 9,000 feet in the Drainage, most of which falls as winter snow (72). Approximately 20 inches of snowfall is equal to 1 inch of water in the winter months and in the spring a ratio of around 12:1 can be expected (15).

Water

All of the water originating within the Porcupine drainage drains into the Gallatin River. Forest Service figures show 22,099 acre feet of water per year coming out of the Porcupine watershed (69). Generally, peak flows occur between late May and early June when spring runoff is at its peak. In 1969 the peak flow occurred on May 20 and was 316.31 cfs. (43).

Geology

The Upper Gallatin Valley is a slightly depressed tract of sedimentary and igneous rocks within the Madison, Gallatin uplift. Porcupine Creek is a synclinal valley within this depressed tract. The area is bounded on the north by the Spanish Peaks fault and fold which exposes crystalline Precambrian rock. Within the drainage, sedimentary and volcanic strata attain an aggregate thickness of approximately

22,000 feet. Over most of the area these beds have been only moderately deformed into anticlinal and synclinal folds. The drainage contains large areas of active and inactive mass movements. Soils are derived mostly from Jurassic and Cretaceous shales and impure sandstones. The soils developed from these types of materials tend to have a high percent of clay-sized particles and a small percent of quartz material (62).

Flora and Fauna

The Porcupine drainage is generally tree covered. However, large expanses of open grasslands and mountain meadows are included. A variety of grasses, forbs, shrubs, and sedges are common to the meadows. Vegetative cover is sparse in the higher elevations of the unit.

Commercial forest lands generally occur from creek bottoms up to approximately 8,400 feet, with most between 7,000 and 8,200 feet (69). The major commercial habitat type is Alpine fir, Grouse Whortleberry with lesser amounts in the Douglas fir, Pine Grass and Douglas fir, Snowberry habitat types. Douglas fir, Lodgepole pine, Spruce, and Alpine fir are dominant timber types (69).

The age of the timber varies from 125 to 200 years. It is almost all overmature with an average age of 180 years. There are no large areas of young growth timber. The overall condition of the timber is classified as overmature and declining in vigor (69).

The last major fire recorded in the area was in 1880. Since 1880, only one significant fire has occurred and this burned approximately 468 acres of grassland at the mouth of Porcupine Creek in 1959. Timber reportedly regenerated rapidly following earlier fires in the area (69).

Elk is the dominant big game species of the area. There is a variety of other wildlife which inhabit the area. Mule deer, moose, big horn sheep, black and grizzly bear, blue and ruff grouse, cougar, martin, mink, weasel, coyote, bobcat, skunk, badger, snowshoe hare, uniqua ground squirrel, pocket gopher, pika, red squirrel, white-footed mouse, mole, shrew, wood rat, bald eagle, hawk, owl, duck, brown, rainbow, and cutthroat trout, and whitefish are the more significant species. ((69) and personal observation.)

Current and Historic Use of Porcupine Creek

The entire Porcupine drainage is presently undeveloped except for a trail system and a few primitive roads and structures. The area has been used primarily for dispersed type recreation. Hunting of elk has probably been the major recreation attraction.

The majority of the domestic livestock was removed from the area in 1919, with only recreational livestock allowed after 1950 (69).

Some selective logging took place in lower Porcupine during the winters of 1949 and 1950 (69).

METHODS

Effect of Logging

It was determined that, in view of the available facilities at Montana State University for forestry research, with no anticipated immediate logging in Porcupine Creek, without a controlled or experimental logging operation elsewhere in the Gallatin, and with the time limitations placed on this study, that a review of the literature applicable to Porcupine Creek would be the most adequate method of predicting the effects of logging operations on the environment of Porcupine Creek.

H. Bentley Glass' citing of Francis Bacon's illuminating metaphor:

> "There are increasing numbers of pioneers who dig out new ore but a great and increasing shortage of smiths who might refine and hammer the ore into unifying theories. Mountains of ore are consequently accumulating around the mouths of the mines until it may seem, our future scientists will need only to refine what is already there in order to keep active." (31)

is pertinent to and supports the author's decision. It is advantageous in this study to "refine and hammer the ore" mentioned by Mr. Glass.

Soil Survey and Mapping

The soil survey of the drainage was completed with the use of the conventional soil auger, spades, aerial photos, horses, and backhoe.

When soils previously unidentified in the Gallatin Canyon were located, pits were dug to aid in describing and analyzing soils. Dr. Bruce Leeson and the author spent July of 1972 surveying the drainage. U.S. Forest Service Series E10 (photographed in July of 1962) aerial photos (4 in. per mile) and the U.S. Geological Survey 15 min. Crown Butte Quadrangle were used extensively during the course of the survey. All mapping was done on aerial photos. Use of stereoscopes was beneficial to surveying and mapping. Mapping units were differentiated on the basis of soils and slope. Slope breaks used in mapping were: 0-8%, 8-15%, 15-20%, 20-30%, 30-60%, and 60%. An Abney level was used to determine slopes. Consideration of vegetation, aspect, and slope was used to deliniate boundary lines of the mapping units. Upon completion of the field work (i.e., surveying and mapping), the mapping units were transferred from the photos to 2-inch to the mile base maps of the area for compilation and completion of the final soils map of the drainage.

Laboratory Analysis

Laboratory work was done on each soil series that was mapped in the drainage. All laboratory work was done by the Montana State University Soils Testing Lab. Tests run included determination of: pH; percent sand, silt, and clay; plant available phosphorus (P) and potassium (K); concentration of soluble salts; percent organic matter;

extractable Ca^{++}, Mg^{++}, and Na^{+}. Bouyouco's method was used in mechanical analysis. Available phosphorus was determined by a modified Bray #1 (1 g of soil/50 ml of extracting solution extracted for 5 min.). The cations were extracted by neutral 1 normal amonium acetate. Soluble salts and pH were determined in a 2:1 water to soil extract with electrodes in the sediment for pH determination. Organic matter was determined by a colorimetric modification (600 mm) of the Walley Black Hot Acid Potassium Dichromate Oxidation Procedure. All laboratory data is included in the Appendix.

Soil Profile Descriptions

Detailed profile descriptions were completed for soils mapped in Porcupine that had not been previously described. Dr. Gordon Decker, Dr. Gerry Nielsen, Cliff Montagne, Al Keppner, and the author worked together on completing the descriptions. Dr. Decker (19) is developing a system of using mark sense forms to describe soil profiles. These forms are processed automatically. The computer stores the data and prints out the soil descriptions. Dr. Decker's system was field tested as part of the Porcupine study. Computerized soil profile descriptions are included in the Appendix.

Profile descriptions completed by Olsen, Leeson, and Nielsen, 1971 (50) were used when applicable.

Soil Limitations for Roads

Determination of soil limitations for roads were completed with the aid of the U.S.D.A., SCS Guide for Interpreting Engineering Uses of Soils (70). Slight, moderate, and severe ratings were calculated. Soil drainage class, flooding, slope, depth to bedrock, AASHO or Unified Group index, shrink-swell potential, susceptibility to frost action, stoniness and rockiness classes were used to determine the limitations or suitability ratings for roads.

Soil Erodibility

K-factors (soil erodibility factors) were determined using Wischmeir, Johnson, and Cross's Guide for Developing the Soil Erodibility Factor (K) in the Universal Soil Loss Equation (77). Percent of silt plus very fine sand, percent of sand greater than 0.10 mm, soil organic matter content, soil structure (type, grade), and soil permeability were considered in determination of the K-factors. Individual horizons of every soil series in the area were assigned a K-factor. K values for lower soil layers are needed to estimate soil losses where surface layers have been removed due to excavation or erosion.

Sediment Sources Areas

Sediment sources were located primarily by field observation and use of aerial photos. Aside from obvious source areas (landslides, denuded elk range), location of source areas was aided by consideration of the following on-site factors: soils (mainly texture and surface erodibility); surface geology; slope or topography; ground cover; land use; upland erosion; channel erosion and sediment transport; climate; and runoff. In the literature, the nine on-site factors listed above are described as the most pertinent factors to consider in evaluating an area as a sediment source (5,38,48,73). If an obvious sediment source was not mapped specifically, (i.e., a landslide or slump), the mapping units of the general soils map of the drainage were used as boundaries between sediment source areas. Using these units the entire drainage was mapped and rated as a sediment source. The rating of an area as a sediment source was determined with the aid of an SCS system (73). The rating system used is included in the Appendix. The nine on-site factors mentioned previously were given a value for each mapping unit; a rating of a unit as a sediment source was then derived by totalling the values (Table VII).

Sediment Yield

In predicting sediment yields from the sediment source areas of the drainage, the SCS system (73) mentioned in the discussion of sediment source locations was used. The nine factors are generally described, for the purpose of avoiding complexity, as independently influencing the amount of sediment yield. In reality, this is not the case.

The factor rating developed for each sediment source area was converted to sediment yield in acre-feet per square mile per year, by means of a sediment yield factor rating graph (included in Appendix).

Total sediment production of each individual unit of the drainage in an undisturbed condition was then computed. A planimeter was used to measure the area of each mapping unit. The area in square miles was multiplied by the acre-feet of sediment produced per square mile per year. It was assumed that an acre-foot of soil weighed 4×10^6 pounds. Multiplying total acre-feet of sediment per year by 4×10^6 pounds and dividing by 2,000 pounds gives the estimated tons of sediment produced annually from each mapping unit. To obtain total sediment production for the entire drainage, the sediment production of the individual units was totalled. Not all sediment moved will leave the drainage. A delivery curve developed by the SCS (73) predicts 32 percent of the sediment moved will leave Porcupine drainage via Porcupine Creek. Therefore, the total sediment moved was multiplied by 0.32 to obtain an estimate of sediment delivered to the Gallatin River by Porcupine Creek.

Certain assumptions had to be made in order to predict sediment yield following logging. Nick Finzer of the U.S.F.S., Gallatin Ranger District, stated that only 15 percent of Porcupine drainage would be allowed to be disturbed at any one time (25). This means a maximum of 15 percent of the total area would be allowed to be clearcut, roaded, or disturbed by present logging or previous logging activities that were considered to still be acting ecologically as a logged, roaded, or disturbed area. Finzer also stated that only 15 percent of any subdrainage would be allowed to be disturbed at any one time (25).

In deciding that 15 percent of the drainage would be allowed to be disturbed at any one time, the percent increase in water yield that would accompany varying degrees of vegetation manipulation was predicted by Finzer. These percent increases were then evaluated in terms of existing channel conditions, soil stability, economics, etc., to arrive at a risk factor. The degree of risk that could be tolerated was decided upon and the 15 percent figure assigned.

With this in mind, using U.S.F.S timber types (69) for Porcupine Creek as a guide, 15 percent of the drainage was selected to be roaded and logged. Those areas chosen for logging are shown in the Results section herewith. Table X lists the units chosen for logging and the percent of each unit that will be logged.

The same procedure was used for determining sediment yields following logging as those used for prediction of yields in the undisturbed (summer of 1972) condition, referring to the method used in Appendix I will aid understanding of the discussion that follows. It was assumed that a 5 percent increase in upland erosion, channel erosion, and sediment transport would occur if 15 to 30 percent of any unit was logged, so +2 was added to the factor rating. A 10 percent increase in upland erosion, channel erosion, and sediment transport was predicted if 30 to 50 percent of a unit was logged, +5 was added to the factor rating. A 15 percent increase was predicted if greater than 50 percent of a unit was logged, +7 was added to the factor rating.

Ground cover and land use were the other characteristics considered to be affected by the logging activity. For each 10 percent increase in logging activity of a unit, +2 was added to the numerical value of the two factors. Calculations are included in the Results section (Table VIII).

The percent increase in sediment following logging was found by dividing the sediment yield increase following logging by the sediment yield produced in the undisturbed condition.

Slope Map

A slope map was prepared using the following procedure: Work was done on 2-inch to the mile base maps which have one contour line for each 80 foot rise in elevation. Slope is defined as vertical rise divided by horizontal distance. Therefore, for a slope of 10 percent on the 2-inch to the mile base map:

$$\frac{80'}{800'} = \frac{\text{Vert. Rise}}{\text{Horiz. Dist.}} = 10\%, \text{ or } \frac{80'}{0.10} = 800' \text{ horizontal distance}$$

A 20 percent slope would equal $\frac{80'}{0.20} = 400$ ft, or an 80 foot rise divided by a 400 foot horizontal distance.

The horizontal distance calculated by the above procedure is divided by 5,280 feet (the number of feet in a mile) and multiplied by 2 (2-inches to the mile base maps were used); this value will be in inches. The values calculated in this way are equivalent to the distance between contour lines on the base map for the particular slope considered. Table I shows the results of the calculations.

Table I. Distance Between Contour Lines on Two-Inch to the Mile Base Map for Different Slopes.

2% slope = 1.536"
5% slope = 0.606"
9% slope = 0.336"
15% slope = 0.202"
30% slope = 0.101"
60% slope = 0.0504"

These values were marked on a transparent scale and used to determine slope on the 2-inch to the mile base map. Distance between contour lines was compared to the distances marked on the scale. For example, if the distance between two contour lines was greater than 0.202 inches, but less than 0.336 inches, this would be an area with a slope of between 9 and 15 percent. If the distance between contour lines was greater than 0.101 inch but less than 0.202 inch, the area would be classed as having a slope of between 15 and 30 percent.

Stream Discharge and Suspended Sediment of Porcupine Creek as a Percent of the Gallatin River

To determine the percent of the Gallatin River flow contributed by Porcupine Creek, the water discharge figures at Porcupine Creek obtained from a Forest Service gauge approximately one mile upstream from the river were compared with U.S. Department of Interior figures (75) for Gallatin River water discharge near Spanish Creek. Only one year's discharge figures were available for Porcupine Creek. Total acre-feet of water leaving Porcupine drainage was compared to acre-feet of water flowing by Spanish Creek in 1969.

Tons of suspended sediment can be predicted for a stream if discharge and suspended load are known by use of the equation:

$$\text{SEDIMENT (PPM)} \times \text{DISCHARGE (CFS)} \times 0.0027 = \text{TONS/DAY}$$

This equation is valid according to the U.S. Dept. of Interior (74). Derivation of the equation by the author clarified the procedure for developing the equation.

In order to compare Porcupine Creek suspended sediment yield to that of the Gallatin River, some assumptions had to be made. Suspended load measurements are available for the Gallatin River at Spanish Creek for parts of 1968 and 1970. Discharge is available from 1925 through 1969. Porcupine suspended load measurements were available for parts of all years between 1967 and 1972. Discharge, however, is only available for Porcupine Creek in 1969.

Records were most complete for 1968 but discharge figures for Porcupine were not measured that year. Due to this lack of information, only daily comparisons of Porcupine and the River were made. To approximate a particular 1968 daily discharge of Porcupine Creek, the percent monthly discharges that Porcupine Creek contributed to the Gallatin River in 1969 were multiplied times daily discharges of the Gallatin River in 1968. For example, May 14, 1968 discharge of Porcupine Creek was needed. In May of 1969 Porcupine Creek contributed 4.88 percent of the Gallatin River discharge. Thus, the Gallatin River discharge of May 14, 1968 was multiplied by 0.0488 to approximate Porcupine Creek discharge of May 14, 1969.

Using the daily discharges calculated for Porcupine Creek (by the above method) and suspended load data for Porcupine Creek, tons of suspended sediment per day entering the Gallatin River from Porcupine Creek were estimated using the equation discussed previously.

Similar predictions were made for the Gallatin River at Spanish Creek. Comparison of the two values will yield percent sediment contribution of Porcupine Creek to the Gallatin River for the particular day being considered. The procedure is questionable and results should not be interpreted as anything other than crude estimates.

REVIEW OF LITERATURE

Effects of Logging Introduction

Logging operations affect the environment of an area in many ways. A consideration of some effects of logging and of factors contributing to these affects will be included in the review of the literature that follows.

On-Site Factors to Consider

On-site characteristics influence the effects of a logging operation. Geology, soils, climate, topography, and ground cover (type and density) must all be considered. Most significant to this study is the influence of the above factors on runoff and erosion or sediment yield. These impacts will be discussed in this section. Effects on phenomena other than sediment yield are important and will be discussed more specifically later.

Geology can be used to predict soil erodibility by consideration of the soils that will develop from certain parent materials (1). Profiles in mountainous terrain tend to be shallow and immature and in many instances characteristics may be inherited directly from parent materials (21). Dyrness states that soils derived from acidic igneous rocks are especially erodible (21).

The SCS classifies surface geology according to its erodibility. Marine shales and related mudstones are classified highly erodible. Rocks of medium hardness, moderately weathered and moderately fractured are classified moderately erodible. Massive hard formations are classified non-erodible (73).

Soils have varying resistance to erosion. Factors influencing both infiltration and permeability, and those soil properties affecting the resistance of soil particles to detachment and transport affect erodibility.

It has been found that larger water stable aggregates are less susceptible to erosion than small stable aggregates (79). Organic matter is an important cementing agent in the formation of large water stable aggregates. As such, soil organic matter content is closely related to measures of soil erodibility (21). Studies reported by Woolridge (79) indicate that 50 percent of the variation in mean aggregate size of surface soil is accounted for by variation in organic matter content.

Organic matter is also important in maintaining optimum infiltration and permeability. However, organic matter may reduce porosity and permeability in some sandy soils. Meeuwig (47) hypothesizes that organic matter may contain constituents that coat the sand-sized particles and render them water repellent. Clay, which has a much greater surface area per unit weight than sand, tends to dilute and reduce the effectiveness of water repellent constituents of organic matter. Thus, infiltration is inversely related to the ratio of organic matter to clay.

Bulk density plays a big part in infiltration. Water retention and infiltration are decreased with increasing bulk density. When a large proportion of the soil is composed of particles and aggregates greater than 0.5 mm, the effect of bulk density is minimal. When the soil is fine and poorly aggregated, water retention and infiltration decrease sharply as bulk density increases (48).

Anderson (1) and Trimble (68) report that stoniness and organic matter of the soil tend to decrease erodibility. Anderson (1) reports an increase in erodibility with an increase in percent silt and clay. Wischmeir (77) and the SCS (71) report an increase in silt-sized particles being especially conducive to erodibility.

Ions adsorbed on the exchange complex in the soil may have a strong influence on erodibility by causing either flocculation or dispersion (23,76). A study reported by Dyrness (21) indicates that calcium and magnesium have a positive and significant correlation with soil erodibility.

The effects of climatic factors on soil erodibility are varied. Temperature, precipitation, and particularly the distribution of precipitation influence the quantity and quality of ground cover as well as soil development. The quantity and intensity of precipitation determine the amount and discharge rates of runoff and resultant detachment of soil. The precipitation is eventually a transport medium for sediment yield.

Snow appears to have a minor effect on upland slopes relative to rainfall (73).

Soil detachment is caused by rainfall impact and is therefore influenced by the kinetic energy of rainfall which varies with drop velocity and mass (73). The transport of detached soil particles in overland flow is controlled by runoff amount and turbulence, both of which are to some extent functions of rainfall intensity. The SCS rates storms of several days duration with short periods of intense rainfall, and frequent intense convective storms as most conducive to high sediment yield (73). Beaseley (15) reports that soil losses, when all factors other than rainfall are held constant, are directly proportional to the total kinetic energy of the storm times its maximum 30-minute intensity.

In some areas the action of freezing and thawing is important in the erosion process. Impermeable ice forms in areas of fine textured soils where a supply of moisture is available before the advent of cold weather. Under these conditions the ice often persists throughout the winter and is still present when the spring thaw occurs. In some instances, water tends to run over the surface of the ice and not detach soil particles, but it is possible for the ice in a surface layer to thaw during a warm period and create a very erodible situation. Spring thaws with ice at shallow depth may wash away the loose material on the surface (73).

In some areas, particularly those underlain by marine shale, freezing and thawing may alter the structure of soil near the surface by breaking up stable aggregates and thus change infiltration characteristics (73).

Watershed slope, relief, floodplain development, drainage patterns, orientation (aspect), and size are basic items to consider in connection with topography. Their influence on sediment yield is closely related with geology, soils, and cover.

As the slope becomes steeper, the velocity of the runoff water increases and this results in an increase in the power of runoff water to detach particles from the soil mass and to transport them (5,10).

The soil loss per unit area increases as the slope lengthens; this results from the greater accumulation of runoff as the slope length increases (5).

Willen (76) reports a decrease in development of silt and clay-sized particles with an increase in slope gradient. This was attributed to slope effect on soil water drainage. Soil formation was thought to be retarded under the more xeric conditions of steep slopes than under the more hydric condition of the gentle slopes. Also reported was a significant increase in erodibility of soils with increasing elevation.

Floodplain development and reduction in relief ratio will cause a reduction in sediment yields as the yields are interrupted by temporary deposition.

Aspect (watershed orientation) plays a big role in the relative sediment yield of an area. Willen (76) reports that erodibility is greatest on westerly exposures, south exposures are reported more erodible than northerly, and easterly exposures least susceptible to erosion. West slopes were about 1.3 times as erodible as east.

Bethlamy (7) conducted a study in central Idaho to determine the effects of exposure on runoff and erosion. Runoff and erosion were greater on southwest than northeast exposures. The results were attributed to greater fluctuation of air and soil temperatures, more frequent freezing and thawing, and less ground cover.

Watershed shape and size may or may not materially affect the sediment yield per unit area. Branson and Owen (10) report long and narrow watersheds contributing greater sediment yields than circular drainages with earlier and greater peak discharges in circular watersheds. The different responses of runoff and sediment yields to circularity are explained by: channel losses and evaporative losses being greater in long, narrow watersheds because of time and travel; and slopes of long, narrow watersheds tending to be steep and thus supplying more energy for sediment transport.

Generally, the sediment yield is inversely related to watershed size because the larger areas usually have less overall slope, smaller proportions of upland sediment sources, and more opportunity for the deposition of upstream derived sediments on floodplains and fans. In addition, large watersheds are less affected by small convective-type storms. However, under other conditions the sediment yield may not decrease as the size increases. There may be an increase of sediment yield as the watershed size increases if downstream watersheds or channels are more susceptible to erosion than upstream areas (73).

Ground cover is described as anything on or above the surface of the ground which alters the effect of precipitation on the soil surface and soil profile (73). Included in this factor are vegetation, litter, and small and large rock fragments. A good ground cover dissipates the energy of rainfall before it strikes the soil surface, delivers water to the soil at a relatively uniform rate, impedes the surface flow of water, and promotes infiltration by the action of roots within the soil. Conversely, the absence of ground cover leaves the land surface open to the worst effects of storms. Dyrness (21) indicated that, contrary to widely held beliefs, the beneficial effects of litter cover may not be due so much to its water absorbing capacity as to its action in protecting soil from the destructive action of raindrops.

Positive and significant correlations have been established for percent bare soil and runoff (10,47,48,51). The correlation for percent bare soil and sediment yields are not as good. Branson and Owen (10) report that the poorer correlation for sediment yield is possibly due to a storing of sediment on ground cover.

A factor inversely correlated with sediment yields is the weight of litter or ground cover. With increasing weight of ground cover, sediment yields are reportedly decreased (10,48). Willen (76) reported that soils under grass were more erodible than soils under brush, which were more erodible than soils under pine.

Meeuwig (48) and Packer (53) stress the importance of litter in maintaining good infiltration and soil stability. Meeuwig, working in northern Utah, reported infiltration being affected significantly by vegetative or litter cover as it was critical in maintaining low bulk densities and good soil aggregation. Seventy-three percent of the variance in soil water retained and thus not available for runoff was accounted for by differences in ground cover and its affect on bulk density and aggregation of the mineral soil.

Packer (53) reported that 93.8 percent of the variances in bulk density of the soils of Tepee Creek in the Gallatin Canyon were the result of ground cover differences. Packer also found that on soils with bulk densities of less than 1.04, corresponding to a 70 percent ground cover, accelerated soil erosion on winter elk range in the Gallatin Canyon did not occur. In 1951, Packer (51) had reported that size of bare openings was the most influential characteristic affecting soil erosion.

Meeuwig (48) estimated that in northern Utah, 65 percent ground cover was a minimum to prevent erosion. Meeuwig (47) reported that 90 percent ground cover was required for erosion protection on Coolwater Ridge in Idaho.

According to Dyrness (21), the greatest deterent to soil erosion is ground cover.

Logging Disturbance, Soils and Sediment

In order to discuss the effects of logging operations, it is important to differentiate between various logging methods. Mr. Bob Cron of the Gallatin National Forest gave the following descriptions of various logging methods (18).

Tractor logging is generally considered the most destructive of the logging methods. Large rubber-tired vehicles (tractors, bulldozers) which attempt to get as close to fallen timber as possible are used. Logs are hooked to the tractor by cables and skidded to yards. The vehicles leave roads depending upon terrain. This method is usually limited to slopes of less than 40 percent.

The jammer method involves using a large piece of equipment (jammer) that is placed on the bed of a truck. The jammer has a cable attached to it which is used to remove fallen timber from the surrounding area. Up to 400 feet of cable is used. The jammer remains on roads and skids timber out of the surrounding terrain using the cable.

High lead or cable logging has a radius of use of approximately 400 yards. Cables are suspended from tree tops or poles specifically used for the purpose. Logs are hooked to the cables and skidded out of the forest. Skyline logging is similar to the high lead method except for the fact that logs are suspended in air for transport with only the butt touching the ground. Much larger spars (poles) are used for suspending the cable and distances of up to a mile can be covered. This method requires approximately 10 percent of the roads required for tractor and jammer methods.

Aerial logging can remove fallen timber without the use of on-site machinery. Aerial methods are excellent for areas of steep terrain.

Dyrness (21), in a report during the International Symposium on Forest Hydrology, cited many examples which indicate that the major factors determining the effects of logging are: type of logging, intensity of cut, and on-site characteristics. The discussion following Dyrness' report indicated near unanimous agreement.

Packer (53) reported the effects of various logging activities on water quality. The following conclusions were drawn from Packer's review of the literature. 1) Cutting of timber in itself does not appear to affect water quality adversely; however, some evidence indicates that the increased streamflow resulting from timber cutting may cause streambank erosion and thereby increase sediment production. 2) Skidding logs from the forest, especially with equipment that deeply disturbs the soil mantle, often increases sediment production. This depends upon the location of skidways with respect to watercourses, the adequacy of drainage facilities, and the magnitude of streamflows. In forests on stony soils, sedimentation rates caused by logging usually decline toward prelogging levels within a few years because a protective stony erosion pavement develops on skid trails and roads. On fine textured soils, rates of sediment production may continue at accelerated levels until skidways become revegetated. This may take only a few years in moist forests or many years in forests having unfavorable growing season moisture. 3) Roads on which surface runoff can concentrate due to inadequate drainage facilities, or roads that are located too close to water courses to accomodate the needed width of intervening buffer strips are without doubt the main source of poor water quality in forests. Roads traversing steep slopes and unstable areas are another significant source of sediment production. Roads undeniably have the most significant effect on sediment production of any logging activity.

Anderson (1) states that roads eventually occupy 6 percent of each logged watershed, as an average, in the Northwest. In Oregon watersheds, if roads occupy 6 percent of the area, sediment production is predicted to increase by a factor of four (1). Eighty percent of the increase is associated with road development and 20 percent with logging independent of roads.

A study conducted in California reported poor logging of 1.4 percent of an area increased sediment by 26 percent. Conversion of

0.6 percent of the area into low standard roads increased sediment by 24 percent (1).

Different logging operations have different effects upon sediment yields. A comparison of logging methods and their effects on the soil and factors leading to sedimentation follows.

Megahan and Kidd (45) reported a sediment production increase of from 0.04 tons per square mile per day for Skyline-Crane logging to 10.76 tons per square mile per day associated with jammer logging. The increase in sediment with jammer operations was attributed to the greater number of roads used in jammer operations. There was tremendous slumping and sliding reported following the operations; most of this damage was associated with roads. The problems were most often related to improper construction.

Jammer roading on steep areas (greater than 35% slope) reportedly disturbed 25% of the total area logged. Skyline logging reduced the area disturbed by 75 percent and provided a greater buffer for sediment between strips. The conclusion was that the greatest benefit from Skyline-Crane methods was fewer roads.

Garrison and Rummell (30) reported one-third of an area logged by tractor was disturbed by roading and skidding. Fifteen percent of the area had deep soil disturbance. Most disturbance was attributed to ground skidding of logs, construction of spur roads, and use of landings. A comparison of tractor and cable methods was made. Twenty-one percent of the area logged with tractors had exposed mineral soil, and 15 percent of the area where cable methods were used had exposed mineral soil.

Woolridge (78) reported tractor logging exposed mineral soil on 22.2 percent of his study area compared to 5.4 percent left bare by Skyline-Crane logging. If this is true, tractor logging left approximately 128 acres of bare soil per section and Skyline approximately 35 acres per section.

Dyrness (22), in a study conducted in the Oregon Cascades, compared tractor and high lead logging. Tractor logging caused a considerable increase in the area of compaction (9.1 to 26.4 percent) plus a corresponding decrease in the amount of undisturbed area (57.2 vs. 35.6 percent). Tractor logging reportedly resulted in the deposition of large amounts of loose soil such as skidroad berms. Dyrness (22) reported tractor logging resulted in the surface 2 inches being three times as compacted in the tractor logged area, with a corresponding decrease in porosity. The tractor logged area had approximately 63 percent pore space compared to 77 percent in an undisturbed state. This decrease resulted in lower infiltration rates and larger amounts of surface runoff. A 15 percent increase in bulk density reduced permeability by 93 percent.

Steinberg and Gessel (64), studying the effects of tractor logging in Southwestern Washington, reported extensive surface disturbance due to the network of skid trails required for yarding. Primarily compaction with a resultant reduced non-capillary pore space increased the bulk density of the soils. Permeability reductions of 34.9 percent were reported as an average for the cutover area. On skid roads, permeability was reduced an average of 92.3 percent. All roads showed evidence of severe compaction and an average increase in bulk density of 34.9 percent. Increase in bulk density for the entire area was 2.4 percent. Tractor roads showed a decrease in macroscopic pore space of between 28.3 and 65.9 percent with an average of 52.9 percent decrease in pore space.

Fredriksen (27) compared the effects of different logging activities on three watersheds in western Oregon. High lead-cable methods were used on one 250 acre watershed which was patch-cut; 6 percent of this area was roaded (1.65 miles) and 25 percent logged. Skyline logging with no road construction was used on an adjacent 250 acre area that was completely clearcut. A control was included in the study. High lead logging with roads resulted in double the area of soil disturbance (10%) and nearly three times the area compacted. Soil loss from the patch-cut was 109 times the loss measured from the control watershed. By far the greatest volume of this sediment (93%) was associated with road construction. Soil loss from the clearcut watershed (without roads) was 3.3 times the loss from the control. Mean annual sediment loss of 7,980 tons per square mile for the patch-cut was 26 times the loss of 307 tons from the clearcut watershed.

The effect of intensity of logging activity is significant. Haupt (34) reported an increase of from 5 to 18 percent in bared soil (29 to 114 acres per section) when selective cut was increased from 1500 to 6500 stems per square mile. Similar increases in intensities of group cuts increased the range from 5 to 13 percent of the area (29 to 84 acres per section). The greater increase in disturbance under stem selection was attributed to greater dispersion of felled trees and less repeat usage of skid trails and haul roads. In the group cuts, as the amount of timber removed increased, the skidding and roading increased with a resultant increase in soil disturbance.

Erosion is greater for heavily used roads than for lightly used roads. According to Trimble and Weitzman (68), as each load of logs passes, part of the soil is carried down the hill and part is compacted. Also, each succeeding load of logs continues to disturb the soil to greater depth.

Compaction reduces macroporespace, water enters slower and aeration is poorer. In a study conducted in the northwest (68), comparing infiltration rates on a skid road with an undisturbed site, it took 32 units of time for water to enter the undisturbed soil and 614 units of time for the same amount of water to enter the skid road.

The deeper the disturbance or the deeper that soil is exposed by roading, the poorer the natural structure. As a result, revegetation and infiltration rates are slower and soils erode for a longer time. As would be expected from the above, post logging erosion is reportedly heavier for heavily used roads (68).

Steinberg and Gessel (64) reported examples of the effect of different intensities of use under differing conditions. Working in the Pacific Northwest they found that four trips with a 50,000 pound crawler reduced the soil permeability by 80 percent and the macroscopic pore space by 50 percent when the soil was dry. When the soil was wet, one trip had the effect of four under dry conditions. Also reported was a study in New York. One trip with an empty farm truck with the soil moisture content at 23 percent increased the bulk density from 1.32 to 1.50. When the soil moisture content was 19 percent, four trips increased the bulk density from 1.24 to 1.58. Soils containing greater amounts of organic matter were compacted to a lesser degree by the same force at the same water content (64).

Periodic disturbance keeps the road surface rough and subject to continued erosion. Roads continually used do not become stable and resistant to the erosive action of water (68).

Erosion is much greater during than after skidding, as it is impossible to maintain adequately spaced surface drainage ditches during skidding.

On-site factors may affect the intensity of use. On steep terrain, operators build additional roads rather than skidding further to landings. Dyrness (22) reports that skid roads will occupy approximately 30 percent of an area with slopes greater than 30 percent if tractor logging is used. Megahan and Kidd (45) report that jammer road construction may disturb up to 30 percent of an area with slopes greater than 50 percent.

Land Instability

Soil mass movements are usually the direct result of the interaction of soil and slope properties characteristic of much of the Rocky Mountains. Dyrness (23) and Swanston (65,66) include parts of Montana as an area highly suspect of mass movement (Fig. 4). The topography has high relief with steep slopes and narrow inter-valley ridges. Locally glacial erosion, tectonic uplift and subaerial processes are credited with further steepening slopes and creating

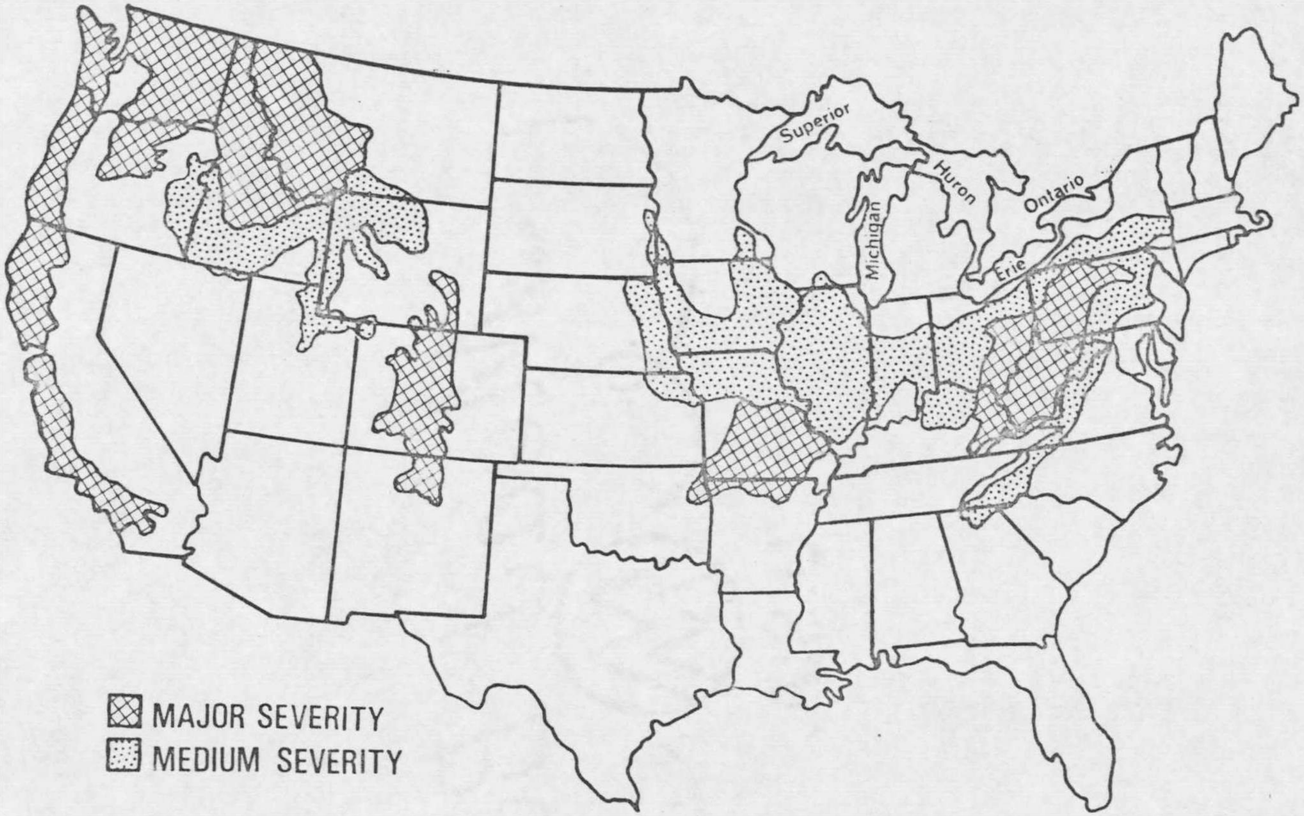

Fig. 4. Aerial Extent of Landslide Problem Areas. Swanston 1971 (66).

unstable natural conditions (66). In such areas, soil mass movement is the dominant process of erosion. The general effect of logging, road building, and fire is to disrupt the delicate balance of forces acting on the slopes, often resulting in further initiation and acceleration of mass wasting.

From the available evidence, the principal effect of timber removal seems to be largely related to removal of surface vegetation, creating conditions conducive to increased soil water content and progressive deterioration of stabilizing root systems (66).

Root systems of trees and other vegetation can serve as cohesive binders or, if they penetrate entirely through the soil zone, can anchor the soil mantle to the substrate and thus provide an effective stabilizing influence. In some extremely steep areas this may be a dominant factor in shear strength of the soil. Shear strength tests on roots taken from clearcut units of a variety of ages in southeast Alaska have indicated a marked decrease in strength three to five years after cutting, a time period that roughly corresponds to the lag between time of logging and massive debris avalanching (65).

Failures associated with road building are largely the result of side casting and addition of road fill, inadequate or poorly designed road drainages, and oversteepened back slopes. Side casting and the addition of road fills may overload the surface below the road cut and obstruct upslope soil drainage, creating saturated conditions in and above the road fill during periods of high runoff. Poorly designed culvert systems and deep cross drainages, coupled with plugging of drainage by debris may also create saturated conditions in and above the road fills. Oversteepened back slope cuts remove support for the soils upslope (66).

As a result of poorly designed road drainage systems and the possibility of increased soil moisture, soil cohesion may decrease due to destruction of capillary tension. Rising pore water pressures also reduce shear strength as a result of decreased effective weight of the soil mass. At the same time, seepage pressures resulting from frictional drag of water flowing downslope through the soil may add significantly to the tangential component of shear stress. In highly cohesive soils increasing water content may also help to mobilize the clay particles through saturation and further add to increased creep rates and even ultimate failure (65).

Slash burning may decrease stability by leading to a progressive deterioration of mechanical stabilizing root systems. Burning also reduces evapo-transpiration with a resultant increase in soil water.

Examples lend credibility to the above discussion. Fredriksen (27), in a study of three small Western Oregon watersheds, found by far the greatest soil loss as a result of logging was associated with landslides and the scouring action of high-velocity mudflows which often pass down stream channels following a landslide. In fact, 97.7 percent of the sediment yeild from a patch-cut watershed resulted during the winter season when 32 landslides occurred during a storm with a return interval of 100 years. Landslides associated with roads in the patch-cut created 93.3 percent of the total volume. These landslides occurred most often where roads intersected stream channels. Clearcutting apparently had a much smaller influence on the occurrence of landslides. Little soil loss was attributed to surface erosion.

Dyrness (23), in an investigation of causes of mass soil movements on the west flank of the Cascades in Oregon, found that more than 72 percent of these events occurred in connection with roads that occupied less than 2 percent of the forest area. Seventeen percent took place on disturbed logged areas which comprised less than 14 percent of the area. Less than 11 percent of these mass movements occurred in undisturbed areas in spite of the fact that more than 85 percent of the forest area was undisturbed. More than 46 percent of the movements were on 60 to 90 percent slopes and 83 percent were on 45 to 90 percent slopes (34% of the area). In Idaho, 90 percent of the soil mass movements which occurred along the South Fork of the Salmon were reported to be the result of slope failures along road right-of-way (65).

Anderson (1) reports that 54 percent of the slides in a general survey of western Oregon were associated with roads, 24 percent were associated with logged areas, and 22 percent with undisturbed areas.

Swanston (65) reports recent increases in soil mass movement following high intensity storms in the Wasatch Mountains are attributed to loss of mechanical support of root systems, the result of logging and burning.

Soils differ in their susceptibility to mass movement. Paeth (55) discusses some of the soil properties that affect instability. An inverse relationship was found between shear strength and cation exchange capacity. Kaolinite, illite, and montmorillite were found to be resistant to shear in the order listed--kaolinite being the most resistant. This corresponds to the inverse relationship to C.E.C. A lack of correlation between stability and most exchangeable ions was attributed to the overriding influence of clay mineralogy and other factors. There was a reported increase in resistance to shear with an increase in iron, aluminum, and hydrogen ions. In a study in which clays were saturated with cations, shear strength increased in the following progression: lithium, sodium, potassium, ammonium, rubidium, and cesium.

Vegetation-Manipulation Effect on Water Yield

An increase in water yield has been attributed to various factors following logging. Reduced interception with resultant reduced re-evaporation at the crown canopy is one factor. Reduced transpiration loss of water extracted from the soil by plants and given off to the air as water vapor is a second factor causing increased yields (60).

Hoover and Leaf (37), in a study in Colorado, concluded that redistribution of snow is the chief cause of increased runoff following cutting. Snow has been shown to accumulate in forest openings, either natural or created by artificial means, to a greater extent than under a forest canopy. Hoover and Leaf (37) state: 1) The concentration of snow pack on portions of the watershed increases the efficiency of delivery of water to stream courses and ground water storage. After initial soil moisture deficiencies are satisfied, more melt water is available to streamflow. One area having a possible deficit and another a surplus, rather than both being just satisfied, reportedly creates greater runoff. 2) Another effect of redistribution of snow to open areas is to place it where initial soil moisture deficiencies are least. Cutting of timber reduces the amount of soil moisture withdrawn during the growing season, resulting in less water needed for recharge in the spring and more available for streamflow. 3) Melt rates are more rapid in openings than in forests. Snow evaporates for a shorter time and melt water tends to be released at a time when there is continuity of flow in surface and subsurface channels. Melting in openings is concentrated into fewer hours of the day as it is less influenced by absorption and re-radiation of incoming heat by forest cover. The result is to reduce total evaporative losses in openings during the melt period.

If snowmelt from openings is synchronized with melt from forested areas, increases in peak flow can be expected and flooding may result. If melt is not synchronized, peak flows may be reduced.

Packer (54) did an excellent job of discussing the effects of elevation, aspect, slope steepness, and forest cover in relation to time of snowmelt and snowmelt rates. The study was conducted in northern Idaho and western Montana.

Snowmelt generally begins later at higher elevations. For each 100-foot rise in elevation, snowmelt reportedly begins 1.2 days later and the average snowmelt rate increased 0.014 inch per day.

Each 10° change of aspect from south to north delayed snowmelt an average of one day and increased snowmelt rate 0.020 inch per day at 5,500 feet.

On a southerly aspect of 160°, each 10 percent decrease in slope steepness resulted in an average rate increase of 0.060 inch per day at 5,500 feet. Snowmelt began an average of 3.5 days later for each 10 percent decrease in steepness. Snowmelt rate increases associated with decreasing steepness of south-facing slopes became progressively larger with increasing elevation. As the aspect shifted from southerly to westerly exposures, snowmelt rate increases associated with decreases in slope steepness became progressively smaller. The snowmelt rate on northerly exposures increased with steepness. A 10 percent increase in slope steepness on a northerly aspect delayed snowmelt an average of 3.5 days and the rate of melt increased an average of 0.103 inch per day at 5,500 feet.

A 10 percent increase in canopy density postponed snowmelt an average of 1.1 days on a south (160°) aspect and 0.4 days on a north (360°) aspect.

Reductions in cumulative diameter of standing timber increase snowmelt rate at low elevations with greatest increases on southerly exposures. At higher elevations, increases in snowmelt rate occur on southerly aspects, reductions in rate occurred on northerly and westerly exposures, with a 60 percent decrease in cumulative diameter.

Clearcutting of the most dense forest stands on southerly aspects at low to intermediate elevations provides largest increases in snowmelt rates. Partial cutting of timber on northerly aspects at intermediate to high elevations affords the best opportunity to effect reductions in snowmelt rates.

Tremendous increases in water yield following logging are rare unless a catastrophic climatic event takes place or a large percentage (greater than 40 percent) of a watershed is logged at one time.

Rothacher (60) and Goodell (32) reported that small areas being clearcut by present logging methods probably will not affect the water yield of a drainage greatly. If the soil moisture has been limiting, the surrounding timber will expand its root system into the area. In effect what happens is fewer trees may use an amount of water nearly equivalent to that used prior to harvest.

If on-site increases in water yield occur, most will reportedly decline rapidly as revegetation begins to take place (36). Pereira (56) reported that bare ground and litter remaining after logging accounts for a third as much evaporation loss as that used by the transpiring crop. Adding weeds and regrowth would account for even more water use.

Rothacher (60) reports that under conditions of the Pacific Northwest, on the west slopes of the Cascades where soils are relatively deep, precipitation is high (75+ inches/year) and recharges the soil each year; and when evapotranspiration rates are fairly high, an 18-inch increase in streamflow could be expected following complete clearcutting and burning. This large on-site increase may be largely obscured on large watersheds harvested on a long-term, sustained yield basis. Rothacher (60) estimates that an 18-inch on-site increase would be equivalent to about an 0.8-inch increase from an area being patchcut on a 100 year rotation.

Because less water is available for plant growth and vegetation is less dense in much of the area east of the Cascades (Montana, Idaho), there is less potential for on-site increases in water yield following timber removal (60).

If a large percentage of a watershed is logged (greater than 40%), substantial increases in runoff may occur (60). Seasonal streamflow may be most significantly affected. Increase in flow during the growing season due to savings in evapotranspiration showing quickly in streamflow are probably most likely to occur on the eastern side of the Rockies (36). Increase in minimum streamflow of late summer may thus be a result of removal of vegetation.

Under certain climatic conditions the effects of vegetation removal can be catastrophic. Vegetation has its greatest effect under dry conditions. West of the Cascades big floods do not occur until soils are thoroughly wet (60). East of the Cascades high intensity summer storms result in "gully washers" which scour the streambeds. These storms occur under relatively dry antecedent conditions. Forest vegetation may greatly reduce flood flows under these conditions. If adequate vegetation is not maintained, increased water flow results in increases in erosion, specifically streambank erosion (53).

Soil Chemistry

In discussing the effects of logging operations on the nutrient budget of a forest ecosystem many factors must be considered.

The timber produced on a watershed has certain mineral requirements for growth. Nitrogen, potassium, phosphorus, and calcium are usually the elements limiting growth. Sulfur, magnesium, and iron are needed but are seldom limiting. Boron manganese, zinc, and copper are needed in very small amounts (63).

On an average site the forest takes up in the neighborhood of 200 pounds of ash constituents per acre per year, except for pine which absorbs about 75 pounds. Of this amount only about 50 percent consists of the essential nutrients potassium, calcium, and phosphorus (4).

Trees can grow well in soils low in nutrients. Being deep-rooted and long lived, trees utilize a large mass of soil to great depths. The ability of a tree species to grow satisfactorily on soils of low nutrient status depends largely upon its relatively slow growth rate (63).

The amounts of nutrients taken up yearly by forests per acre are less than those taken up by the average field crops (4).

Table II. Relationship Between Uptake, Retention, and Return of Mineral Nutrients for Forest Compared to Agricultural Crops.

	Taken Up	Retained	Returned
N - Agriculture	100	75	25
N - Forest	40	8	32
K - Agriculture	70	20	50
K - Forest	15	4	11
Ca - Agriculture	40	10	30
Ca - Forest	60	10	50
P - Agriculture	25	20	5
P - Forest	10	2	8

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*Figures are in pounds/acre/year (4).

The above table supports reports by Youngberg (80) and Baker (4) which state that very small quantities of the nutrients taken from the soil are deposited in the bole wood which is the source of timber. The greater part is in leaves and fine twigs which fall as litter or remain after commercial logging as debris and litter.

The weight of litter fall in open coniferous forest stands of the west is estimated at between 1,000 and 3,000 pounds per acre per year (dry weight). Up to 50 years' accumulation may take place in cool, dry areas such as the Rocky Mountains. Considering the entire soil profile, Baker (4) estimates that around 200,000 pounds of organic matter may have accumulated. Nitrogen composes about one percent of this. Only one to two percent of this is available at any one time. Ash constituents of the litter on the forest floor are incidental and variable.

The nutrients present in a forest ecosystem have arrived by various processes. The atmosphere: precipitation, dust, or fixation by organisms is one source; mineral weathering (cations and phosphorus) is another source. Biological inputs are an additional source. Losses from the system may occur as dissolved and suspended constituents in streams, by removal of materials from the land, and by volatilization to the atmosphere (28).

Nutrient status is affected by land use. Streams draining undisturbed forest systems contain constituents not taken up by vegetation, either lost by leakage from the inner cycle (nutrients returned and reused by vegetation) or released by weathering (28).

Nitrogen loss from undisturbed watersheds is very small. Losses of cations are also small and controlled by the quantity of mobile anions which enter the soil solution. Bicarbonate anions formed by hydrolysis of carbon dioxide released by respiration of organisms, are a principal anion source (28).

Nitrogen, phosphorus, and potassium inputs in precipitation may balance the losses from the system in drainage waters. Anions in precipitation may accelerate leaching losses; fortunately, concentrations of anions in precipitation are generally small (28).

In logged ecosystems, trees no longer take up nutrients and the non-merchantable parts of trees increase forest litter. Increased temperature and water content of the soil accelerate the activity of micro-organisms that break down forest litter. The greatly increased respiration activity of the system raises the bicarbonate anion level and leaching loss of the system. Nitrogen loss as nitrate may occur where mineral nitrogen released by decomposition or organic materials is not utilized by plants or micro-organisms (28).

Fredriksen (28) reported a summary of information concerning nutrient output from three experimental watersheds in western Oregon. Complete clearcutting with burning and an undisturbed condition were compared.

Losses of dissolved chemicals were calculated by the product of concentration and streamflow. Annual streamflow from the clearcut watershed for the period of study (1966-68) was 1.5 times the control and was attributed to timber removal. Annual losses of cations and bicarbonate exceeded the previous losses primarily due to an increase in streamflow (Table III). Maximum increases occurred during the year following burning.

Table III. Total Annual Dissolved Chemical Loss in Streams Draining Clearcut and Control Watersheds (lbs/A).

	Logging Only		Following Slash Burning			
	1966		1967		1968	
Chemicals	Clearcut	Control	Clearcut	Control	Clearcut	Control
NH_3-N	----	----	1.34	0.025	0.010	0.000
NO_3-N	0.23	0.07	0.62	0.025	2.15	0.007
Na	30.8	18.6	31.7	16.8	----	----
K	4.8	3.0	5.4	2.8	3.1	1.6
Ca	54.3	23.6	72.7	23.5	54.7	21.4
Mg	14.0	5.0	23.4	6.7	14.3	4.3
PO_4-P	0.27	0.19	0.49	0.13	----	----
HCO_3-C	51.3	25.0	64.0	31.0	35.5	20.7

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[*] Taken from Fredriksen 1970. Forest Land Uses and Stream Environment, Pg. 133.

Nitrate loss from the clearcut watershed at the completion of logging was 3.3 times the loss from the control watershed. Loss of nitrogen was greatly accelerated following slash burning and was nearly equal at 2 pounds per acre for both years. Losses from the control stream amounted to 0.05 pounds per acre in 1968. Loss of inorganic phosphorus from the clearcut was much smaller than nitrogen loss and proportional to the streamflow increase in 1966. The loss after slash burning was 3.8 times larger. Though the increases were small, the potential for impact is large in streams because of low phosphorus content.

Nutrient chemicals also entered the stream attached to mineral sediment and as constituents of organic sediment materials. Large increases in loss of all chemicals are evident for both years (Table IV). A reduced loss in 1968 was largely the result of lower sedimentation. Suspended sediment loss was 14 times the control in 1967 but dropped to half that amount in 1968. Loss of organic nitrogen on sediment averaged 54 percent of the total loss for the two years combined. Potassium was 17 percent of the two-year loss.

Results of this study indicate that the loss of chemical nutrients from the terrestrial system of the forest into the aquatic system of the stream increased following logging and slash burning. The increased loss was attributed to: 1) a reduction in transpiration

Table IV. Annual Loss of Chemical Constituents Adsorbed on Mineral Sediment plus that Contained in Suspended Organic Material (lbs/A).

Following Slash Burning

	1967		1968	
Chemicals	Clearcut	Control	Clearcut	Control
Organic N	3.4	0.14	1.7	0.14
K	1.1	0.023	0.7	0.022
Ca	2.8	0.2	1.4	0.4
Mg	1.7	0.027	1.0	0.027
Mn	1.4	0.02	0.7	0.02

---

[*] Taken from Fredriksen 1970, Forest Land Uses and Stream Environment, Pg. 134.

and hence an increase in the amount of water passing through the system; 2) by simultaneously reducing root surfaces able to remove nutrients from the leaching waters; 3) adding to the organic substrate available for immediate mineralization; and 4) in some instances, producing a microclimate more favorable to rapid mineralization.

The importance of the losses from certain terrestrial systems will vary. Loss of the principal cations may not be important where elements are supplied in large quantities by chemical weathering. Annual losses of some nutrients may be balanced by inputs from precipitation. Baker (4) estimates 5 pounds of nitrogen per acre per year enter the system through precipitation. Fredriksen (28) estimates nitrogen entering the system via precipitation to be less than 2 pounds per acre per year in the Pacific Northwest. According to a study by Fredriksen (29), nitrogen is the only nutrient in which input by precipitation may balance losses through streamflow. Potassium and phosphorus inputs by precipitation have been reported to balance loss through streamflow in other studies (28).

Stream Temperature

Stream temperature is dependent upon total heat received (11). The principal source of heat is solar energy striking the stream surface directly. Conduction, convection, and evaporation have a smaller effect on temperature (12).

Vegetation, topography, stream channel flow characteristics, inflow of surface and ground water, plus area, depth, and velocity of the stream influence the amount of heat reaching a stream (11).

Temperature change produced by a given amount of heat is inversely proportional to the amount of water heated, or the discharge of the stream. Magnitude of the temperature change varies directly with the surface area exposed to the sun; thus wide, shallow channels heat fastest.

Maximum stream temperature in the Northwest can be expected in July and August when air temperature is high, solar radiation is intense, streamflow is low, and water movement is slowed (41).

Riparian vegetation plays the greatest role in determining the rate at which solar energy reaches small mountain streams (12). Vegetation is accordingly important in reduction of extremes in temperature fluctuation.

Temperature change induced by a logging operation is mainly the result of vegetation removal. Predicting the temperature change induced by timber removal is difficult if only partial stream cover is removed. Predicting the effect of complete shade removal is not so difficult. Brown (12) reported the following formula for predicting temperature change following complete vegetation removal:

$$\Delta T = \frac{A \times H}{D} \times 0.000267$$

where: ΔT = temperature change expected by completely exposing a given amount of stream
A = stream surface area exposed in square feet
H = given heat load in (BTU/ft^2/min) stream is exposed to
D = discharge in cfs
the constant 0.000267 allows conversion of ft^3 of H_2O to pounds so that ΔT will be in °F.

No reports of use of the equation were found.

Examples help to illustrate the effect of timber removal on water temperature. Brown and Krygier (11) report that exposing 1300 feet of a stream with a discharge of 1 cfs increased water temperatures by 16°F. The large affect is attributed to low flow and large surface area exposed.

Brown (12) compared a clearcut watershed which had accumulated logging debris in the stream to another which had been scoured by a flood and was completely exposed. The scoured stream had temperature increases from 7-12°F compared to a maximum increase of 4°F for the stream containing logging debris.

Levno and Rothacher (42) compared complete logging and burning with an undisturbed forest. Monthly averages increasing by 13°, 14°, 12°F were recorded for the burned watershed in June, July, and August, respectively.

Brown and Krygier (11) report an increase in annual maximum temperature of 28°F following complete exposure of a stream in the Oregon Coastal Range. Discharge, however, dropped to 0.01 cfs in late summer.

Without complete shade removal, less severe changes result. Brown (12) reported no change when a 50 to 100 foot buffer strip was excluded from a clearcutting operation in Oregon.

Levno and Rothacher (42) reported no evidence of stream temperature change at the mouth of a drainage in the H. J. Andrews Experimental Forest when 25 percent of the area had been logged and burned. Only limited stretches were exposed to direct sunlight. Two years later, however, a flood scoured the main stream channel to bedrock and removed all streamside vegetation. The following summer, increases up to 16°F were reported.

Brown, Swank, and Rothacher (13) reported increases of 4°F after 100 percent of a drainage was clearcut but streamside vegetation was undisturbed. After the entire drainage was burned and approximately 2,000 feet of stream channel cleared of debris, a 12°F increase was recorded.

Levno and Rothacher (41) reported that until greater than 55 percent of a watershed was logged in Oregon, no statistical evidence of stream temperature change was found. In the study, intermittent stretches were exposed to sunlight.

The cooling effect of shaded portions of a stream has received considerable attention. The literature contains studies indicating no cooling effect, and of cooling of up to 8°F in a 700-foot shaded stretch (11,12,41).

Statements by Levno and Rothacher (42), and by Brown, Swank, and Rothacher (13) provide a good review of the above discussion of the effects of logging on stream temperature. The temperature regime of a stream may be changed when timber harvest removes the shade provided by streamside vegetation. Increases in temperature are related to the amount of shade removed and surface area exposed to direct sunlight. The change in temperature is primarily due to energy increases created when the low intensity, diffuse light of a stream under the forest canopy is changed--by canopy removal--to direct solar radiation. Removing all shade can increase daily water temperature 10°F and more. Shaded reaches downstream can not be relied on to cool heated streams. Buffer strips do help control stream temperature fluctuations.

Aquatic Life

Debris and sediment that are a result of logging activity can have a significant effect on the aquatic life of a stream.

Sediment affects the aquatic population in different ways. In suspension, sediment blocks light transmission reducing the depth at which photosynthesis can occur. This reduces the amount of algae that might eventually be converted to food for fish or other aquatic organisms.

Sediment in suspension can be heavy enough to kill fish directly by damaging their gills. The wide variation in test results make it impossible to say what level will kill fish. Size, shape, and hardness all influence the effect of suspended sediment particles on the gills of fish. In general, it can be said that suspended sediment concentrations must exceed 200-300 ppm for many days before any direct mortality results (57).

Settled sediment influences survival of aquatic organisms in several ways. First, it can reduce survival by filling the interstices in the gravel bed, thus reducing the exchange of oxygen-rich surface water with oxygen-deficient water within the gravel bed. This exchange is necessary to assure sufficient oxygen for insect respiration, decomposition of plant and animal material and incubating fish eggs. If flow of water through the gravel of a stream is inhibited, less removal of metabolites results in concentrations of CO_2 and ammonia, which are toxic to aquatic organisms (49). Settled sediment may also create a physical barrier to emergence of young fish and other aquatic organisms.

If sediment contains a high percentage of organic matter, decreases in the dissolved oxygen content of the water may result. As organic matter breaks down, it has a high biochemical oxygen demand, caused by the respiration of bacteria, protozoa, and fungi. A chemical oxygen demand is also exerted by soluble substances such as wood sugars, as they are leached from the debris (49).

There are examples of sediment disrupting the aquatic balance of a stream. Packer (52) reported that sediment deposition on the bottom of Taylor Fork of the Gallatin River had resulted in reduction of insect production vital to trout survival in the stream. Narver (49) also reported sediment disrupting the aquatic balance of a stream in Oregon. A fine layer of debris and silt had reduced oxygen concentration and oxygen interchange in the substrate.

In undisturbed watersheds, however, normal sedimentation is not dangerous to aquatic organisms (17). Sediment increases that are produced by seasonal storms are usually accompanied by streamflow sufficient to limit stream deposition. Graham agreed with the above and stated that in streams like those in the Gallatin Canyon angularity of the gravel is very advantageous in prevention of physical barriers being developed and conducive to good oxygen interchange (33).

Flooding and scouring is a problem. Physical destruction of the gravel environment and smothering reduce productivity. Continuous small additions of sediment to streams when sediment would not normally be contributed is also detrimental as velocity and discharge may not be great enough to keep the sediment from settling (17).

The above discussion gives some idea of the problems associated with sediment and aquatic organisms, specifically fish. Cordone and Kelley (17) state that consideration of the direct affect of sediment on fish may be wasted. They believe that with what is usually known, it is nearly impossible to predict whether sediment is directly harmful. They state that in most cases, indirect damage to the fish population through destruction of the food supply, eggs, or alevins, or changes in habitat occur long before adult fish are directly harmed.

Aside from possible sediment problems, logging may affect the aquatic flora and fauna of a stream by its effect on chemistry and temperature of the stream.

Little is known about the importance of additions of nutrients to the aquatic system (60). Productivity may be increased depending upon the amounts of available nutrients that can be used to produce aquatic vegetation. Increased sunlight to the stream that results from removal of shade by timber warms the temperature and increases the potential for primary production of aquatic vegetation.

Productivity is an important consideration. Cordone and Kelley (17) mention that undeniably most mountain streams are not very fertile. Increased stream temperatures and nutrients could increase this productivity. The benefits (e.g., larger fish populations), however, were questioned, as it is not known what the total effect of an increase in productivity might be.

Fire

In a year, an acre of forest converts solar energy into vegetable matter equivalent to 300 gallons of gasoline (59). Due to this tremendous and continuous buildup of fuel, forest managers have introduced prescribed burning to eliminate fuels caused by logging and natural timber debris.

The severity of the fire or total heat created at a particular spot has been recognized by researchers as the key to the affect on the soil (3,8,20,26). Generally, the more severe the burn the more severe or drastic the effects. Severely burned areas in prescribed burns generally encompass 5-15 percent of the total burn; light burn, 40-50 percent of the area; and unburned, 30-50 percent of the total burn (20,24,67). Wildfire generally results in a greater percentage being severely burned due to the greater accumulation of fuel and resultant higher temperature. In the research reviewed, only severely burned areas had significant and consistent effects on soil properties (3,8,26,35,39).

Physical and chemical properties are affected by burning. Percent organic matter is reduced by burning (6,8,20) more drastically in those areas experiencing severe burn. Severe slash fires in the Pacific Northwest have been reported to have reduced organic matter content of the surface soil (1-3") up to 60-75 percent (3-24). Affects of the reduced surface organic matter are varied. Erosion increases, (8,44), and infiltration has been reported to increase in some areas (24,61) while decreasing in others (24). Increased infiltration is attributed to elimination of heavy intercepting brush and litter. Decreased infiltration is reported to be mainly the result of soil puddling and resultant surface compaction following near complete litter removal and rainfall (24,39). Crusting caused by heating the soil surface may reduce infiltration.

Tarrant (67) and others (6,35,67) observed marked reduction in percolation rates which is believed to be the result of a reduction in macropore volume following a severe burn (24,35,39). The reduction in macropore volume is a result of destruction of the organic mat, which exposes and allows breakdown of the mineral soil surface structure (6, 35). Pore clogging by suspended materials can cause a reduction in total pore volume. Destruction of soil aggregates by fire and alkaline ash, and subsequent washing in and plugging of larger pores creates an increase in bulk density (24,67).

Moisture holding capacity of the soil, critical for seedling establishment, has been observed to decrease by as much as 6 to 8 times, due to reduction of surface organic matter (3,34).

Researchers have observed a reduction in the percent of clay-size particles following severe burns. It is believed that there is a dehydration of the clay particles near temperatures of 400°C which leads to a progressive fusion resulting in larger particles (20,58). An increase in sand-size particles has accompanied the decrease in fine particles which seems to verify the hypothesis (20,58). In one study, the change in percent fine material was great enough to warrant a new textural class for the soil (20).

The resultant larger particles formed from fusion are defined as "super stable" secondary particles which do not aggregate as well as smaller primary particles (20,58). This combined with the oxidation loss of large amounts of organic matter which is the cementing agent of most forest soils (20,24,39), results in a loss of aggregate size and surface stability. Dyrness (24) reports increasing erodibility with a decreasing aggregate size.

Soil surface temperature following burning is affected. The black, charred layer remaining results in greater heat absorbance by the soil (39). Loss of shading as a result of burning causes more rapid change in temperature and greater extremes (6).

Any type of overstory remaining after burning will reduce the impact of the burn as litter will begin to accumulate at once (16,35).

Chemical changes include a definite increase in pH of the surface soil (3,6,24). Nine hundred degrees Fahrenheit was observed by Tarrant (67) to be the temperature at which maximum pH change occurred.

Increased pH is a result of elimination of much of the acidic organic duff and liberation and resultant availability of bases in the ash. Available calcium, magnesium, and potassium, in that order, increase substantially following a severe burn (6,39).

There is disagreement as to the availability of phosphorus. Beaton (6) believes the phosphorus is immediately tied up by formation of relatively unstable calcium compounds and by the absorption of phosphate ions upon charcoal. Nitrification is stimulated due to an increase in nitrifying bacteria in the alkaline condition and due to a decrease in acidic fungi which inhibit nitrification (26). The C/N ratio is smaller following burning due to a relatively greater reduction in organic carbon than nitrogen. Available N is increased.

Total amounts of all the elements are reduced (3,39). It is believed some of this loss is due to absorption upon suspended particles in the smoke removed by winds.

Release of nutrients is very slow in a natural forest system (6,39). The available nutrients or plant available foods are increased tremendously following a fire. Increased availability does mean stimulation of growth, which is desirable provided young trees do not develop extensive crowns and shallow root systems. A deficiency or return to normal in the nutrient balance in this case could cause a loss of large numbers of seedlings.

A brief review indicates that relatively small areas of soil are severely affected by a prescribed burn and that generally only a severe burn causes consistently adverse effects. Most of the effect of burning is observed in the top three inches of the soil.

RESULTS

Soil Survey and Soils Map

The soil survey of the Porcupine drainage resulted in development of the soils maps included (Figs. 5 and 6). Seventeen different mapping units were established. Six of these were previously unidentified in the Gallatin Canyon. A brief description of the six new soil mapping units is included in the following paragraphs. Descriptions of the other eleven mapping units are available in Soil Interpretations of the Gallatin Canyon (50). The names assigned the new soils are tentative. Numbers following the soil names in the following paragraphs correspond to numbers on the included soils map.

Station soils #26 are found in sections 16 and 22, along the north side of the ridge (Lemon Ridge) extending diagonally through the sections, and extensively in the eastern one-half of section 26. Forested landscapes broken by mountain parks are typical. The unit is composed of Teton (described by Olsen, Leeson, and Nielsen, 1971 (50), and Station soils. The A-horizon is a dark gray to dark brown silty clay loam. Subsurface texture may vary from clay to silty clay loam. Clay increases with depth and a B2t is present. A light gray subsurface with increasing yellow color with depth is typical. The profile contains few fragments and is noncalcareous to four feet.

Porcupine Area

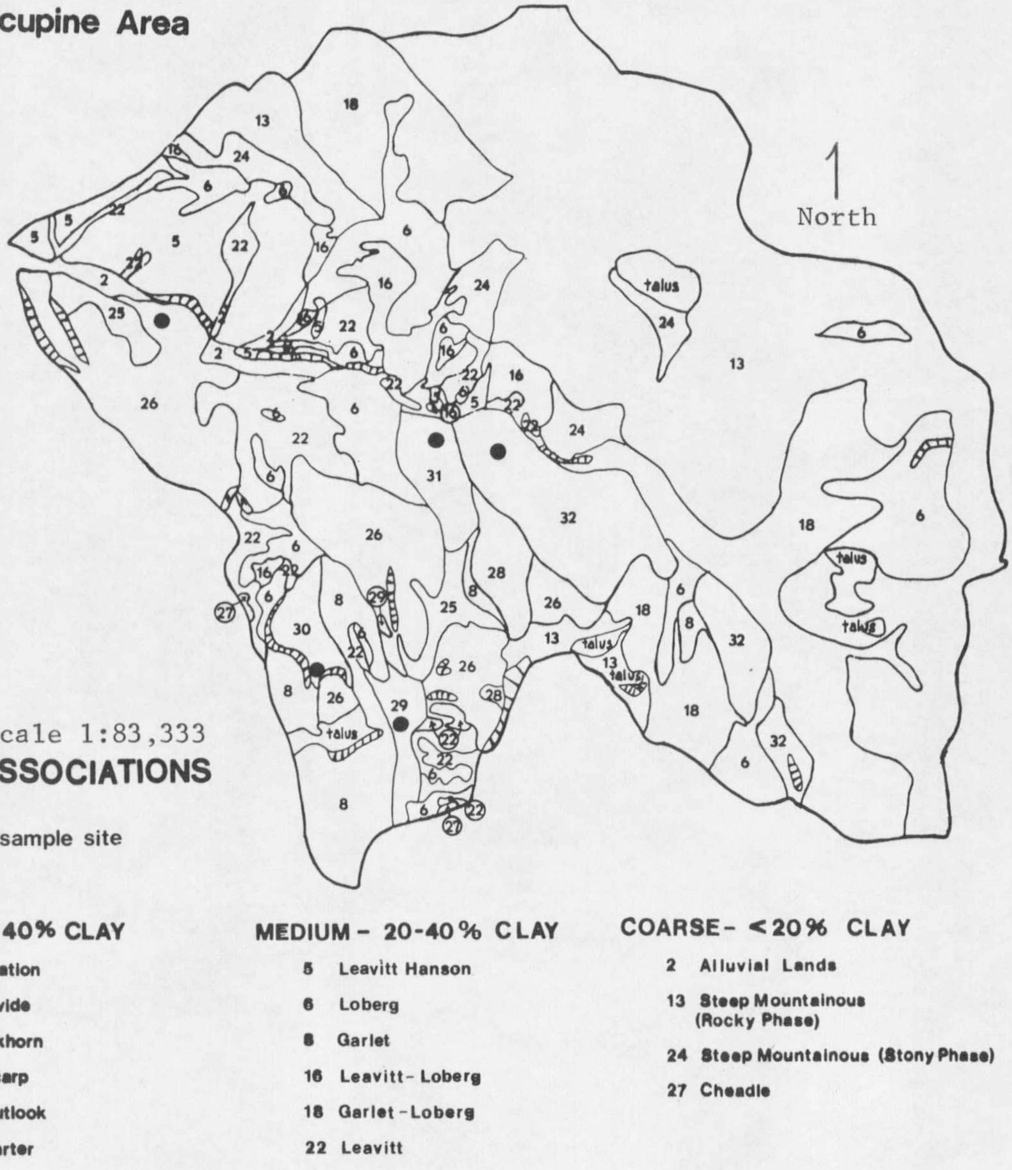

Fig.5 Scale 1:83,333

SOIL ASSOCIATIONS

● soil sample site

FINE - > 40% CLAY

- 26 Station
- 28 Divide
- 29 Elkhorn
- 30 Scarp
- 31 Outlook
- 32 Karter

MEDIUM - 20-40% CLAY

- 5 Leavitt Hanson
- 6 Loberg
- 8 Garlet
- 16 Leavitt-Loberg
- 18 Garlet-Loberg
- 22 Leavitt
- 25 Teton

COARSE - < 20% CLAY

- 2 Alluvial Lands
- 13 Steep Mountainous (Rocky Phase)
- 24 Steep Mountainous (Stony Phase)
- 27 Cheadle

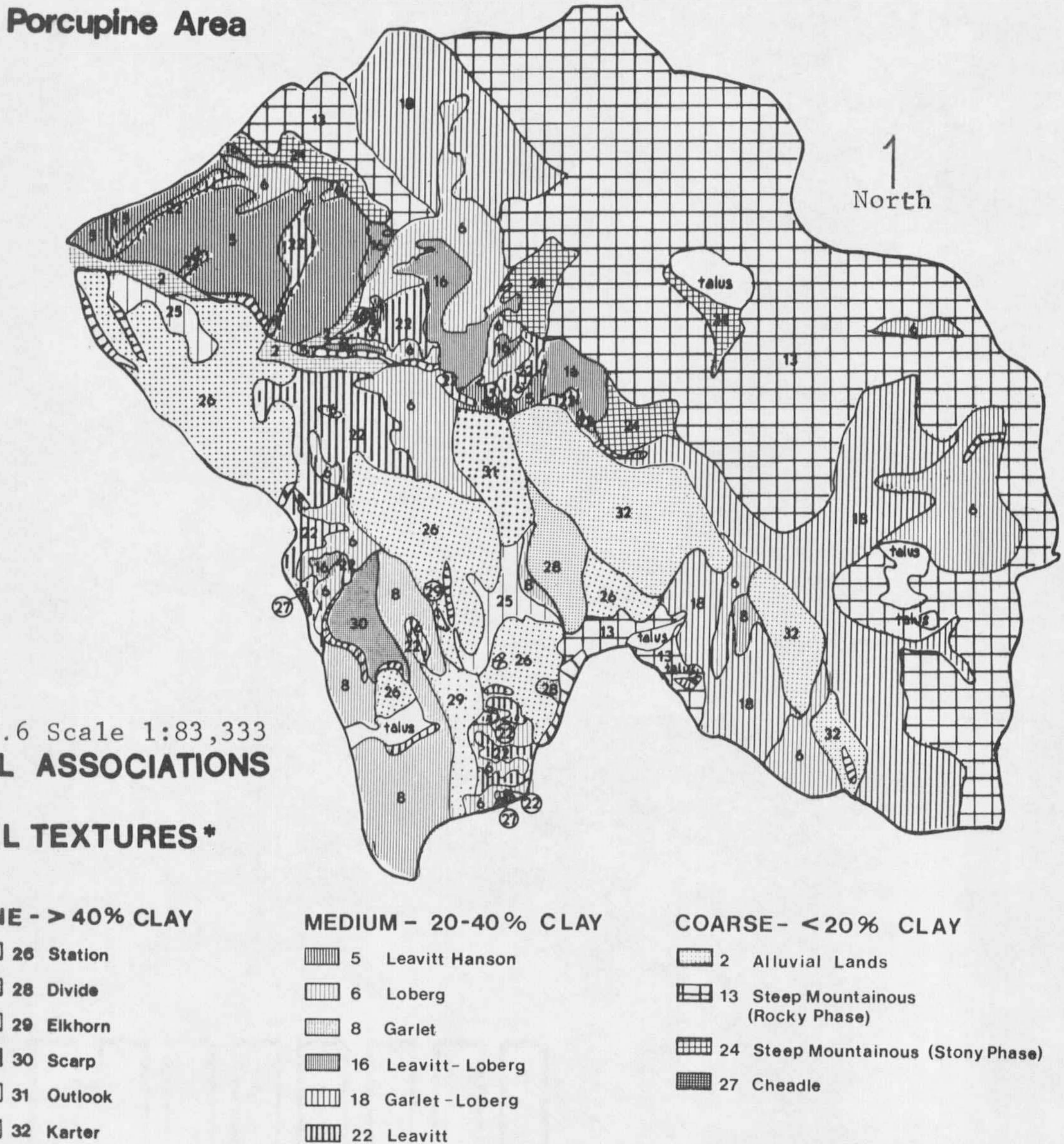

Fig.6 Scale 1:83,333

SOIL ASSOCIATIONS and SOIL TEXTURES*

FINE - > 40% CLAY

- ▦ 26 Station
- ▦ 28 Divide
- ▦ 29 Elkhorn
- ▦ 30 Scarp
- ▦ 31 Outlook
- ▦ 32 Karter

MEDIUM - 20-40% CLAY

- ▥ 5 Leavitt Hanson
- ▥ 6 Loberg
- ▥ 8 Garlet
- ▥ 16 Leavitt - Loberg
- ▥ 18 Garlet - Loberg
- ▥ 22 Leavitt
- ▥ 25 Teton

COARSE - < 20% CLAY

- ▦ 2 Alluvial Lands
- ▦ 13 Steep Mountainous (Rocky Phase)
- ▦ 24 Steep Mountainous (Stony Phase)
- ▦ 27 Cheadle

*Texture Based on % Clay

Permeability was observed to be slow, though the profile is well drained. Station was classified as an Argic Cryoboralf.

Divide soils #28 occur at high elevations below the large escarpment along the watershed south boundary in sections 36 and 25, generally in heavy timber. The profile is well drained with permeability moderate. The profile is typically heavy brown clay containing medium to coarse sand. Sand and coarse fragments increase with depth. Fragments constitute from approximately 20 percent in the surface to 50 percent in the substratum. The profile is noncalcareous. Depth to bedrock is variable but is between 36 and 47 inches. Divide was classified as a Typic Cryochrept.

Elkhorn #29 occurs most extensively in meadows along the trail leading to the Elkhorn divide. A typical example of the soil occurs at the intersection of sections 35, 36, 2, and 1. The surface is a very dark brown, heavy clay loam underlain by a heavy, massive, gray clay in the subsurface. The profile is noncalcareous to a depth of five feet. The soil is well drained with moderate permeability and is essentially fragment-free. Elkhorn was classified as an Argic Cryoboroll.

Scarp soils #30 occur only in sections 35 and 26 of the drainage associated with severe land instability (evidence of recent mudslide). The unit is completely forested. A dark reddish-brown, fine clay loam surface overlies a clay subsoil of varying colors; shades of red and brown give way to a light gray C2 horizon at approximately 17 inches. The profile is well drained with slow permeability, essentially fragment-free, and noncalcareous to six feet. Scarp was classified as an Argic Cryochrept.

Outlook #31 occurs on the flat topped ridge extending from the SW 1/4 of section 24 into the NW 1/4 of section 25. The landscape is forested, broken only occasionally by meadows. A grayish-brown clay loam surface is underlain by a brownish-gray B2t. Fine testure dominates the profile with subsoil texture varying from clay to silty clay. The profile is well drained with moderately slow permeability, and is fragment-free. The profile is slightly calcareous at two feet. Outlook was classified as an Argic Cryoboroll.

Karter soils #32 occur on the large ridge extending from the SW 1/4 of section 24 through the SW 1/4 of section 30. The unit is typically forested. A dark grayish-brown clay loam surface horizon overlies a clay subsoil. The subsoil is reddish purple at higher elevations and more brown at lower elevations. Rock fragments may comprise up to 50 percent by volume of the profile. The profile is well drained with slow permeability and is noncalcareous. Karter was classified as an Argic Cryoboroll.

The other eleven mapping units on the soils map of the drainage are described by Olsen, Leeson, and Nielsen (50). Variations did occur.

Leavitt, on the south side of Porcupine Creek in Unit #22, has a much deeper A1 horizon, up to ten inches, than Leavitt in Unit #5. Most Leavitt on the north side of Porcupine Creek, west of First Creek, has approximately four inches of A1.

Teton soils in the vicinity of sections 25 and 36 develop from a sandy bedrock found on Lemon Ridge (sections 16 and 22). In sections 36 and 25, the bedrock appears to be a sandy conglomerate rather than sedimentary.

Loberg soils mapped in Onion Basin (section 28) are poorly and very poorly drained. This is also the case in most of section 23 that is mapped as Loberg.

In section 23, typical Loberg soil is present near the center of the section. However, as one proceeds south, the Loberg is less typical in that relatively fragment-free pockets of heavy clay are frequently encountered. This is especially true in the area of section 26 containing Loberg.

Lab analysis of all soils in the drainage and profile descriptions of the six new soil series are included in the Appendix. Fig. 6 shows the location of soil pits used in the study.

Soil Limitations for Roads

Using the U.S.D.A., SCS Guide for Interpreting Engineering Uses of Soils (70), ratings were obtained for soil limitations for roads (Table V).

K-Factor

K-factors (soil erodibility ratings) were assigned to all horizons of all soil series in the drainage (Table VI). Wischmeir's guide for predicting K-factors (77) was used in prediction.

Sediment Source Areas

The seven on-site factors, discussed in the Methods Section, were evaluated and a rating factor of an area as a sediment source was derived. The results of the analysis are included in Table VII-- the ratings of the drainage in an undistrubed condition (as it was at the time of study). Table VIII is the rating of the units after logging activity. Only those mapping units affected by logging activity were re-analyzed.

Included in the tables are sediment yield figures in acre-feet per square mile per year. The location of mapping units 1 through 85 are shown in Fig. 7.

Table V. Soil Limitations for Roads

Soil Name	Rating	Reason for Rating
Divide	S-V	Slope
	M	*AASHO
	M-V	Shallow depth to bedrock, unfavorable clay content, slippery when wet, slope
	V	*Unified
Elkhorn	S-V	Slope
	M	AASHO
	V	High shrink swell, unfavorable clay content, slippery when wet
Garlet	S-V	Slope
	M	AASHO, unified
	V	Shallow depth to bedrock
Garlet-Loberg	S-V	Slope
	M	AASHO, unified
Leavitt	S-V	Slope
	M	AASHO, unified
Leavitt-Loberg	S-V	Slope
	M	AASHO, unified
Loberg	S-V	Slope
	M	AASHO, unified
Karter	S-V	Slope
	M	AASHO, Depth to bedrock
	V	Unified, unfavorable clay content, high shrink swell, slippery or sticky when wet

Table V (continued)

Soil Name	Rating	Reason for Rating
Misc Steep Mtns.	S	AASHO, unified
	S-V	Depth to bedrock, slope
	S-V	Slope
Outlook	S-V	Slope
	M	AASHO, depth to bedrock
	V	Unfavorable clay content, high shrink-swell, slippery or sticky when wet
Scarp	S-V	Slope
	M	AASHO
	V	Unified, unfavorable clay content, high shrink-swell, slippery or sticky when wet
Station	S-V	Slope
	M	AASHO
	M-V	Unfavorable clay content, high shrink-swell, slippery or sticky when wet
	V-	Unified
Teton	S-V	Slope
	M	AASHO, unified

Key:
S = slight limitation
M = moderate limitation
V = severe limitation

*AASHO system is used by the American Association of State Highway Officials. Ratings were estimated.

*Unified system is used by the U.S. Corps of Engineers and the U.S. Bureau of Reclamation. Ratings were estimated.

Table VI. K-Factor Predictions

	% Silt	% Sand	% O.M.	Struct.	Perm.	*K	**Final K
Station A1	23.5	25.28	4.7	Med. Gran.	Slow	0.05	0.13
B2t	23.14	14.0	3.0	S.A. Blky.	Slow	0.05	0.16
B23t	36.14	13.06	0.34	S.A. Blky	Slow	0.13	0.25
C1	29.36	27.64	0.15	Massive	Slow	0.14	0.26
Elkhorn A1	36.44	36.64	5.95	Mod. Gran.	Mod.	0.11	0.14
B3	14.0	54.72	0.9	Massive	Mod.	0.07	0.13
C	23.28	64.72	1.4	Massive	Mod.	0.13	0.20
Scarp A1	28.28	24.56	5.1	Fine Gran	Slow	0.04	0.13
B1	31.50	17.42	2.8	Fine Gran.	Slow	0.08	0.16
C1	30.36	10.92	1.1	Massive	Slow	0.09	0.21
C2	29.6	10.04	0.81	Massive	Slow	0.08	0.19

Table VI (continued)

	% Silt	% Sand	% O.M.	Struct.	Perm.	*K	**Final K
Outlook A1	41.78	23.5	5.6	Med. Gran.	Mod. Slow	0.11	0.17
B2t	29.49	13.79	1.3	S.A. Blky.	Mod. Slow	0.08	0.17
C1ca	44.00	11.14	1.0	Med. Gran.	Mod. Slow	0.18	0.24
C2ca	39.06	6.0	0.43	Strong Gran.	Mod. Slow	0.13	0.20
Karter A1	17.56	63.64	5.0	Fine Gran.	Slow	0.05	0.13
B21	21.28	33.28	2.0	S.A. Blky.	Slow	0.10	0.22
B22t	21.39	25.89	1.6	Wedge	Slow	0.06	0.17
C1	25.15	37.21	0.43	Wedge	Slow	0.115	0.24
Leavitt A1	40.00	29.44	5.5	Fine Crumb	Mod. Slow	0.13	0.16
B2	39.28	23.44	2.7	S.A. Blky.	Mod. Slow	0.15	0.24
B3	22.00	37.44	0.71	S.A. Blky.	Mod. Slow	0.11	0.21

Table VI (continued)

	% Silt	% Sand	% O.M.	Struct.	Perm.	*K	**Final K
Leavitt C1	22.00	38.00	1.4	Ang. Blky.	Mod. Slow	0.10	0.20
Teton A1	39.28	14.16	9.0	Fine Crumb	Mod.	0.09	0.08
B21	36.00	17.28	5.3	Ang. Blky.	Mod.	0.08	0.14
B22	29.28	22.16	4.0	Prism to Blky.	Mod.	0.06	0.13
C	28.00	22.00	2.4	Ang. Blky.	Mod.	0.08	0.14
Garlet 1	39.0	28.0	4.7	Ang. Blky.	Mod. Rapid	0.11	0.14
2	30.0	19.0	2.5	Ang. Blky.	Mod. Rapid	0.08	0.12
3	36.0	23.0	2.6	Ang. Blky.	Mod. Rapid	0.12	0.15

Table VI (continued)

	% Silt	% Sand	% O.M.	Struct.	Perm.	*K	**Final K
Loberg A2	20.0	67.0	0.43	S.A. Blky.	Mod. Slow	0.13	0.23
AB	18.0	65.0	0.08	Ang. Blky.	Mod. Slow	0.12	0.22
B2	12.0	71.0	0.15	Ang. Blky.	Mod. Slow	0.08	0.17
C	18.0	55.0	0.15	Massive	Mod. Slow	0.10	0.20

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*K = first approximation excluding consideration of structure and permeability.

**K = final K including structure and permeability.

Table VII. Evaluation of On-Site Factors and Resultant Rating of Sediment Source Areas for Porcupine Drainage in Undisturbed Condition.

Mapping Unit No.	Surface Geology	Soils	Climate	Runoff	Topog.	Ground Cover	Land Use	Upland Erosion	Channel Erosion	Factor Rating	Sed. Yield
# 1	5	1	7	5	18	-8	-10	2	7	27	0.22
# 2	0	5	7	3	10	-3	-10	4	3	19	0.16
# 3	0	5	7	3	10	-3	-10	3	3	18	0.15
# 4	4	4	7	3	10	-8	-10	3	9	22	0.18
# 5	5	10	7	5	15	-3	-10	3	7	39	0.33
# 6	5	10	7	5	17	-3	-10	3	7	41	0.36
# 7	1	5	7	3	10	-3	-10	2	3	18	0.15
# 8	3	4	7	5	10	-3	-10	3	7	26	0.21
# 9	5	1	7	5	18	-8	-10	2	7	25	0.20
#10	5	4	7	3	10	-4	-10	3	7	27	0.22
#11	0	5	7	3	10	-3	-10	3	3	18	0.16
#12	5	10	7	5	18	-4	-10	3	7	41	0.36
#13	5	3	7	5	15	-5	-10	3	7	30	0.24
#14	5	3	7	5	12	-5	-10	3	7	27	0.22
#15	3	4	7	5	15	-6	-9	3	4	26	0.21
#16	2	5	7	5	16	-5	-9	3	3	27	0.22
#17	2	5	7	5	13	-3	-7	3	4	29	0.23
#18	2	5	7	5	11	-5	-7	4	6	28	0.22
#19	2	5	7	5	12	-7	-9	3	3	21	0.17

Table VII (continued)

Mapping Unit No.	Surface Geology	Soils	Climate	Runoff	Topog.	Ground Cover	Land Use	Upland Erosion	Channel Erosion	Factor Rating	Sed. Yield
#20	3	5	7	5	10	-5	-7	3	4	25	0.20
#21	3	5	7	5	12	-5	-8	4	4	27	0.22
#22	3	5	7	5	17	1	-3	7	7	49	0.49
#23	3	5	7	5	14	-2	-5	5	5	37	0.31
#24	3	5	7	5	12	-3	-8	4	4	29	0.23
#25	3	5	7	5	11	-6	-9	3	6	25	0.20
#26	5	4	7	5	10	-5	-10	3	7	26	0.21
#27	3	5	7	5	13	-4	-6	4	7	34	0.28
#28	3	4	7	3	10	-4	-10	5	7	25	0.20
#29	5	5	7	5	20	-0	-8	3	7	44	0.40
#30	5	3	7	5	20	0	-5	3	5	43	0.39
#31	2	5	7	5	16	-2	-5	4	6	38	0.32
#32	2	5	7	5	16	-3	-5	2	7	36	0.30
#33	3	5	7	5	20	-3	-8	4	7	40	0.35
#34	3	5	7	6	12	3	5	7	9	57	0.64
#35	0	5	7	5	13	-5	-8	2	3	22	0.18
#36	3	5	7	6	10	3	5	7	3	49	0.49
#37	2	5	7	6	12	5	5	9	11	62	0.77
#38	0	5	7	3	10	-6	-4	3	6	24	0.19
#39	0	5	7	3	10	-5	0	3	6	29	0.23