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Suspended Sediment Yields in an Undisturbed Western Montana Watershed

by

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the degree of

Master of Science

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Approved by:

Donald F. Potts

Chairman, Board of Examiners

Dean, Graduate School

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Director: Dr. Donald F. Potts DFP

Suspended sediment yields were monitored for three small drainage basins on a granitic intrusion within the Garnet Range. Sediment yields ranged from 0.7 to 26 tons/mi^2/yr. Comparison with other granitic watersheds demonstrated the variability inherent to this geology and suggests that other physical factors may be influencing these rates. The large range of sediment yields between drainages was attributed to inconsistencies in streambed material (consolidated vs. unconsolidated), proximity to an actively eroding access road, and the instability of stream banks along the middle and lower reaches of the main drainage.

Streamflow regions delineated by Potts (1983) for western Montana were used to classify 107 watersheds. Several morphometric characteristics were quantified for each watershed. Discriminant analysis was utilized to test the validity of Potts′ regionalization from a geomorphic standpoint. Sixty-two percent of the watersheds were correctly classified using morphometric characteristics.

Inter-region comparisons of morphometric parameter means illustrated a significant difference between four of the nine chosen parameters. An intra-region comparison of the study watershed parameters with parameter means calculated for the region it resides in, demonstrated exceptions resulting from a lenient sample selection.

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My gratitude is extended to many people who helped make graduate school and this study a reality. In particular, I am indebted to Professor Donald Potts. With foresight, encouragement and advice, he instilled confidence and understanding in times of doubt.

To other members of my committee, Professors Hans Zuuring, Steve Running and Bill Woessner, who donated time, expertise and critical review of this study, my sincere thanks are given.

Special appreciation goes to Diane Daley for her expertise in habitat typing a large watershed inhabited by intimidating moose.

Two additional people deserve recognition and profound thanks, Margaret Hillhouse and Dave Scott. Your contributions in time and labor, both mental and physical, shall not be forgotten. But above this, it was your friendship that I cherish most highly.

Last, but far from least, is my wife. This degree is dedicated to you. Your unending encouragement, patience and sacrifice made this degree possible. For this I am forever grateful.

ORGANIZATION

The two objectives of this study, while closely related, warrant separate discussions:

Chapter I - Sediment yields in the North Fork of Elk Creek - includes a detailed description of the study watershed and an investigation of suspended sediment - discharge relationships and of the spatial and temporal variability inherent to the minimally disturbed watershed.

Chapter II - Testing of regionalization assumptions - compares the North Fork's morphometric characteristics with those of other watersheds thought to exhibit similar water yield characteristics in western Montana.

CHAPTER I

Sediment Yields in the North Fork of Elk Creek

INTRODUCTION

Stream and river sedimentation have been a concern of this country for many years. Total sediment (bedload and suspended load) is not only the major water pollutant by weight and volume, but also serves as a catalyst, carrier, and storage agent of other forms of pollution (Vanoni 1977). In the northern Rockies it has been described as the most common and serious water quality problem in forested watersheds (Rosgen 1975). Desired water quality depends on use and in general, sediment is detrimental to most demands. Sediment impacts municipal supplies, recreation, industrial consumption and cooling, hydroelectric facilities and aquatic life. Additionally, chemicals and wastes can be assimilated onto and into sediment through ionic exchanges between solutes and soil particles (Vanoni 1977). Thus, sediment becomes a ready carrier and storage agent for pesticide residue, absorbed phosphorus, nitrogen, organic compounds and pathogenic bacteria (Branson et al. 1981, Vanoni 1977).

Suspended sediment, in particular, has many problems associated with it. Aside from the high costs of removing it from municipal and industrial supplies, its presence in streams can also be biologically costly. Suspended sediment can affect size, populations and species of fish in streams. Reduction in light transmittance, for example, reduces growth of microscopic organisms which, in turn are fed on by insects and fish. Gill injuries and breathing apparatus impairment to certain species, along with spawning bed deterioration from inwashing of fines are other serious consequences of this pollutant.

The Federal Water Pollution Control Act (PL92-500) classified sediment as a nonpoint source pollutant. This initiated federal mandates concerning acceptable levels of sediment increase and the development of best management practices to minimize man-induced sediment production. Both require knowledge of naturally occurring erosion rates and sediment yields.

In western Montana very little information exists concerning sediment production in undisturbed watersheds. Forest hydrologists, because of this scarcity of local data, must extrapolate information obtained in other regions to Montana watersheds. Consequently, assessment of forest management impacts is heavily reliant on assumptions about similarity between regions. Many sediment models can be found in today's hydrologic journals. In evaluating the limits of these models, it is often emphasized that extrapolation of information from outside sources be done with extreme care. The importance of using local data is repeatedly stressed (e.g. Cline et al. 1981).

The bulk of the literature on sediment production in the northern Rocky Mountain Region comes from research on the Idaho batholith. Models thus developed have been adopted in western Montana for estimating sediment yields despite the differences in lithologies and soils. Rosquist (1977), in developing sediment calculation procedures for the Lolo National Forest, notes, "...without field data representative of our other watershed areas (those not granitic) an empirical method of relating undisturbed sediment production to other watersheds was needed." Erosivities were then developed and expressed relative to granitics. Thus, the Lolo plan has incorporated extrapolated erosion rates, a vital part of a sediment prediction model, into a sediment yield calculation from which future land evaluation and management decisions are to be made. The possible uniqueness of western Montana's watershed never enters the process.

This study gauges and quantifies the natural suspended sediment yield of an undisturbed watershed in western Montana.

OBJECTIVES

Suspended sediment-discharge relationships and variability of two subdrainages and the main drainage of the North Fork of Elk Creek are investigated by:

A. Determining the normality of discharge and sediment yields and applying necessary transformations to achieve normality.

B. Comparing annual and spring sediment yield and discharge means among sub-drainages for significant differences.

C. Developing annual and spring sediment rating curves.

D. Comparing sediment rating curve slopes and intercepts for significant differences.

PREVIOUS WORK AND WATERSHED DISTURBANCES

The North Fork of Elk Creek has been the subject of one previous hydrologic study. Poliquin (1967) constructed a hydrologic budget for the catchment, including precipitation distribution, storm movement, intensities and durations, streamflow, and analysis of groundwater discharge from the watershed. In this investigation three Parshall flumes (one 152 cm., two 122 cm.), a v-notch weir, six groundwater monitoring wells, and three meteorological stations were installed.

There have been no recent disturbances within the watershed. A lightning fire in 1960 burned about 800 acres in the northeastern corner of the drainage. Other disturbances include some small scale selective logging in 1962 and 1965, and an old access road. Since sediment yields from fire and logging have been found to recover, or to return to predisturbance rates, within 10 years (Cline et al. 1981), the North Fork can still be considered a minimally disturbed watershed.

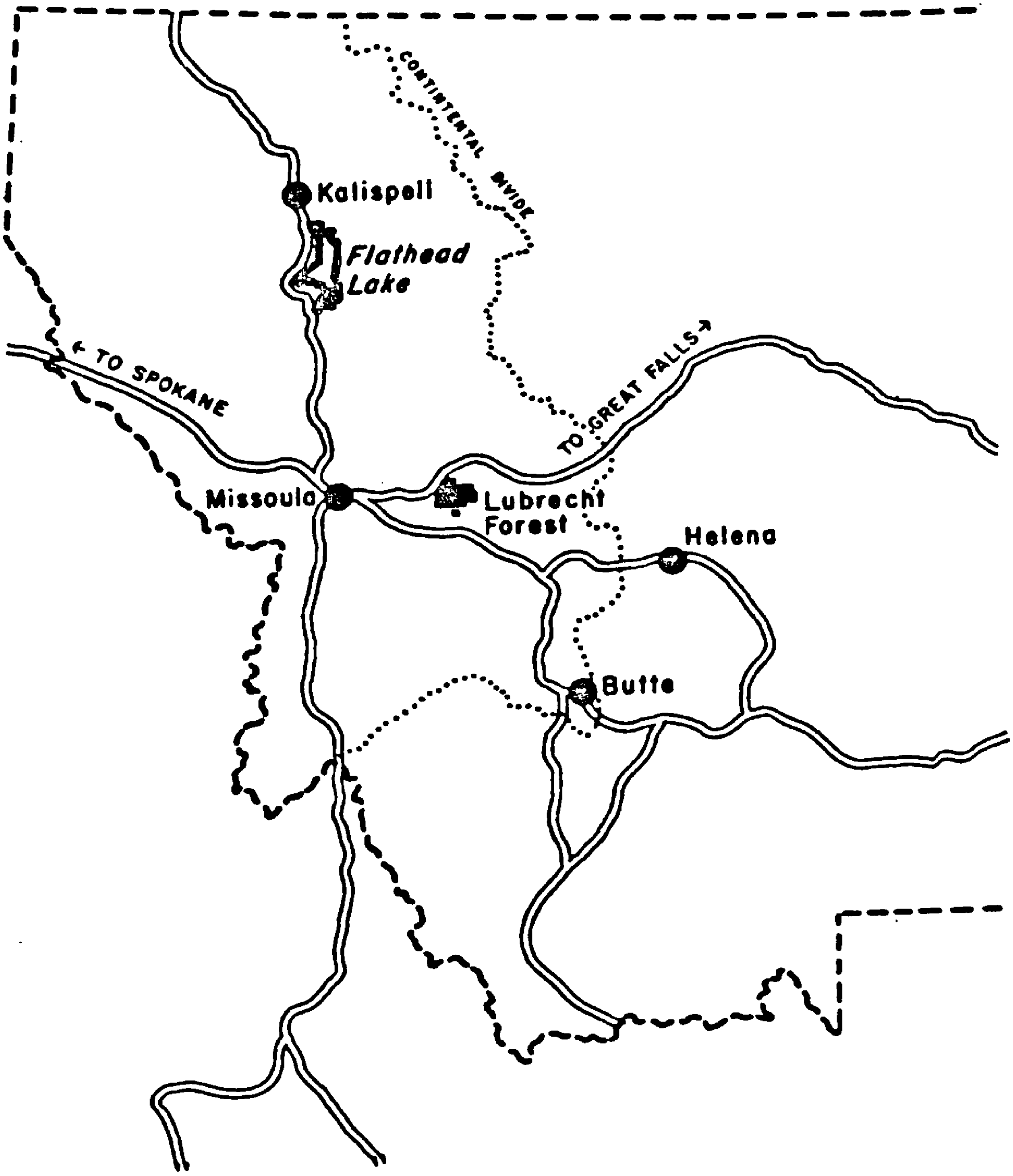
STUDY AREA

Location

The North Fork of Elk Creek is located in west-central Montana, at 46 51'30" N latitude and 113 18' W longitude. The watershed lies within the southeastern border of Lubrecht Experimental Forest, about 72 kilometers due east of Missoula (Figure 1).

FIGURE I

Location Map of Lubrecht Forest



Topography

The North Fork watershed encompasses an area of about 18 square km. Like many watersheds in western Montana it exhibits a dendritic drainage pattern. Relief within the drainage ranges from 2063 meters (MSL) to 1264 meters (MSL), with over 50 percent lying above 1554 meters (MSL) (Figure 2). Orientation is east-west yielding primary aspects of NE and SW resulting from major channel dissections.

Climate

Climate for the North Fork is described as a modified temperate continental regime (USDA Forest Service 1976). Modified temperatures result from maritime influences originating in the North Pacific. This climate differs markedly in severity from that found 100 kilometers away on the eastern side of the Continental Divide. Long-term average monthly temperatures range from -8 C to 16 C.

Precipitation comes primarily during two periods, late spring (May - June) and mid-winter (December - January). Precipitation results from orographic and frontal activity associated with low pressure systems originating off the Pacific coast.

Weather within the North Fork basin has never been monitored for an entire year. In 1964, a study was initiated in which temperature was recorded during a five-month period (May through September) during three consecutive years. Average monthly temperatures during this interval ranged from 6 C to 16 C. The nearest full-time climatological station

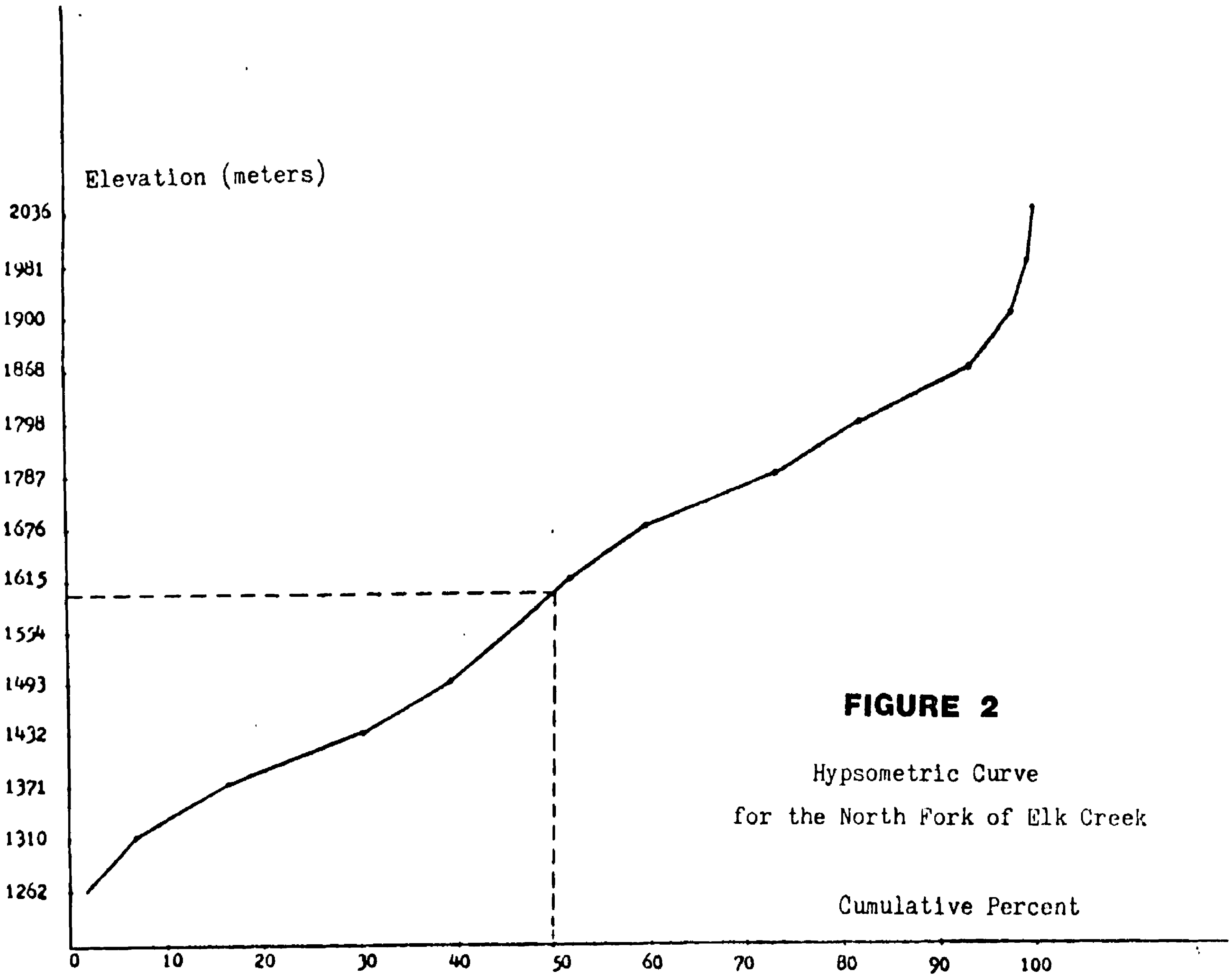
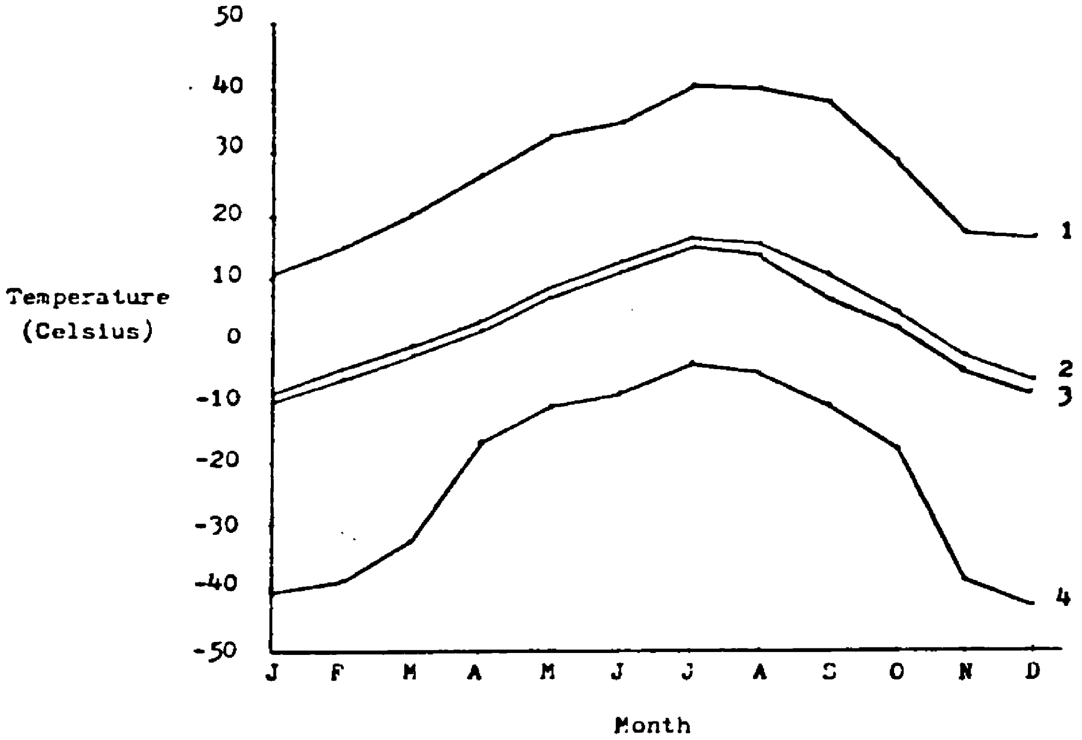


FIGURE 2

Hypsometric Curve
for the North Fork of Elk Creek

FIGURE 3

Monthly Temperature Summary for the North Fork
of Elk Creek and Greenough, MT.



1. Maximum monthly temperature - Greenough Station
2. Average monthly temperature - Greenough Station
3. Average monthly temperature - North Fork of Elk Creek
4. Minimum monthly temperature - Greenough Station

* Taken from: Weather Data Summary Lubrecht Exp. Forest

is located at Lubrecht's Headquarters, Greenough, Montana (elevation 1219 meters MSL), about 8.8 km NW of the Study basin. Twenty-five years of record have been accumulated, yielding a fairly representative picture of Lubrecht's climate.

High vertical relief and complex geomorphology make extrapolation of weather data in mountainous areas very difficult. Modification of local weather by landforms is well documented (Hidore 1972, Lee 1980). Johnston et al. (1972) state that aspect is important because of its influence on radiation, temperature, wind patterns and moisture regimes. Temperature regimes within the North Fork can be estimated by using Greenough´s monthly averages as approximations of temperatures at the mouth of the basin. Only 46 meters separate the two by elevation (1219 meters MSL vs. 1265 meters MSL). Using a lapse rate of 0.7 C per 100 meters of elevation, an estimation of temperatures within the basin can be calculated. Average monthly temperatures recorded at Greenough, with an estimate of the North Fork of Elk Creek to facilitate comparisons, have been plotted in Figure 3. Temperature extremes at Greenough range from a summer high of 40.5 C to a summer low of -5.0 C. Winter extremes range from a minimum of -40.5 C to a maximum of 10.0 C.

Vegetation

Vegetation within the study area is typical of temperate highland forests of this region. Major tree species include: lodgepole pine (*Pinus contorta* Dougl.), ponderosa pine (*Pinus ponderosa* Laws.), Douglas-fir (*Pseudotsuga menziesii* Mirb.), western larch (*Larix occidentalis* Nutt.) and, Engelmann spruce (*Picea engelmannii* Parry) and subapline fir (*Abies lasiocarpa* (Hook) Nutt.) occurring on the moister, cooler sites.

The watershed was classified according to habitat types. The orientation of the drainage helped to accentuate the abrupt change of habitat types occupying the north facing slopes of the southern half and the south facing slopes of the northern half. This natural delineation was less obvious as one moves into the higher elevations of the headwater region. The North-Northwest quarter of the drainage is dominated by South-Southwest aspects which are occupied by *Pseudotsuga menziesii/symphoricarpos albus* - *Calamagrostis rebescens* habitat types, with *Pseudotsuga mensiesii/symphoricarpos albus* - *Agropyron spicatum* found in the drier more open sites. The moister sites and upper draws and ridge tops of this quarter are inhabitated by *Abies lasiocarpa/Linnaea borealis* with occasional changes to *Galium triflorum* and *Mensiesia ferruginea*. The Northeast section of the catchment supported habitat types of predominately *Pseudotsuga menziesii/Linneae borealis* in mostly the *Vaccinium globulare* phase with the *Symphoricarpos albus* phase reappearing on drier southern aspects. Also noted were small areas of *Pseudotsuga menziesii/Vaccinium globulare* - *Xeraphyllum tenax* and *Pseudotsuga menziesii/Symphoricarpos albus* on side slopes throughout the drainage. The southern half of the catchment, dominated primarily by North- Northeast aspects, was generally occupied by *Abies lasiocarpa/ Linneae borealis* habitat types.

The southern half of the drainage is heavily timbered. The lower reaches of the northwest section open up slightly supporting some meadows parallel to the stream channel. Stream bottoms exhibit lush riparian vegetation. Exposed bedrock outcrops, boulders and talus are common throughout the area. Exposed, erodable soil surfaces appear to be few.

Geology

The geology of Lubrecht Forest was mapped in 1964 by Brenner (1964). Structurally, only one major fold occurs within the forest, the east-southeast dipping Elk Creek syncline. This fold is abruptly terminated in the southeast (the area encompassing the North Fork) by the Garnet stock. The intrusive rock mass consists of quartz monzonite which has a tendency to weather into spheriodal, blocky outcrops. These outcrops are readily visible throughout the central and eastern portions of the watershed. The northern divide of the catchment is a transition zone between the edge of the Garnet stock and Cambrian marble overlain by Precambrian Argillite. Small areas of intense mineralization are found along a contact between the quartz monzonite stock and the marble (Brenner 1964). The southwest and mouth of the drainage is also of late cretaceous monzonitic lithology and partially overlain by recent alluvial deposition. The nearest fault ot the study area is the Cap Wallace fault which runs east to west beyond the northern divide of the watershed.

Soils

In 1964, the North Fork was mapped in the Lower Blackfoot Soil Survey by the Soil Conservation Service. Several soil associations were identified: the Winkler-Sharrott, the Ambrant-Rock Outcrop, and the Elkner-Rock Outcrop.

According to this mapping, the North Fork's most abundant soil series is the Ambrant. The SCS describes this soil as being formed in materials derived from granite colluvium. This soil is variable in depth, with moderately rapid permeability and low available water capacity. Its location throughout the drainage is extensive, occupying predominately south-southwestern aspects and the lower reaches. Rock outcrops are common.

The Elkner series is the next most abundant soil in the drainage. This soil is variable in depth, moderately permeable, and has poor available water capacity. Like the Ambrant series, it also originates from granite colluvium and is often found under vegetation that limits the annual wetting depth to about 96 cm. This soil is also found extensively throughout the watershed occupying the heavily timbered northern aspects.

The Sharrott-Winkler series is restricted to the upper slopes of the northern divide. It is a shallow soil, developing from thinly bedded argillite or mixed Belt Series Rocks. Commonly found on moderate to steep slopes, these soils are well drained, with moderate permeability resulting from a high percentage of coarse fragment content.

All three soil series are considered by the SCS to have a high water erosion hazard. Shallow soils, steep slopes and bedrock outcrops are listed as limiting factors that must be dealt with in evaluating or recommending management activities for this drainage.

A more definitive soil mapping of this portion of Lubrecht Forest is currently in the planning stages (Nimlos 1982).

Hydrology

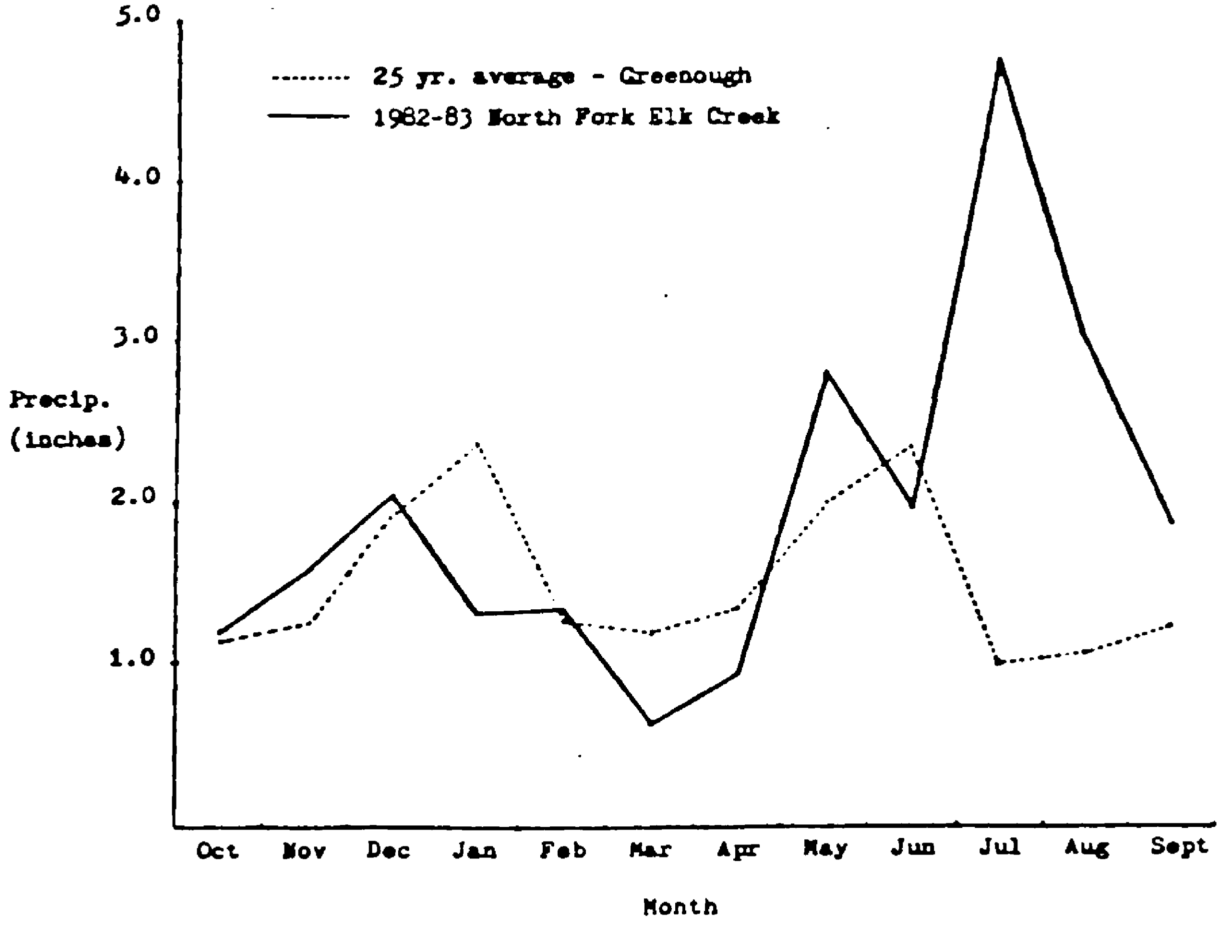
The hydrology of mountain watersheds is as much a function of climate as it is inherent geomorphology (Ward 1975). Climatic factors, i.e., type of precipitation, intensity, duration and distribution, inevitably affect streamflow. In the North Fork precipitation occurs primarily during two periods, spring and early winter. Poliquin (1967) estimated 29.5 percent of the annual precipitation occurred as snow. During this study, precipitation was distributed fairly evenly between winter snowfall (27%) and spring rains (24%). Summer was unusually wet with above normal precipitation being recorded for July and August (Figure 4).

The balance between precipitation received by a watershed versus that lost to evapotranspiration is the most important influence that climate will have on the long term total volume of streamflow (Ward 1975). Evapotranspiration losses for the North Fork were estimated as high as 85 percent of total annual recharge (Poliquin 1967). Precipitation for the drainage during the study interval was estimated at 8,124 ac-ft. Measured annual runoff was 2,663 ac-ft.

Precipitation for a catchment is a short term event when compared to the run-off it generates (Ward 1975). Soil water storage, in response to gravity, slowly discharges excess water after fulfilling soil matrix demands. The rate of this discharge is directly influenced by physical characteristics of the basin. Soil texture, depth, water retention capabilities, hydraulic conductivity and slope have been cited as influencing the rate of interflow (Anderson 1951, Branson et al. 1981, Megahan 1973). Shallow granitic soils of the upper hillslopes and

FIGURE 4

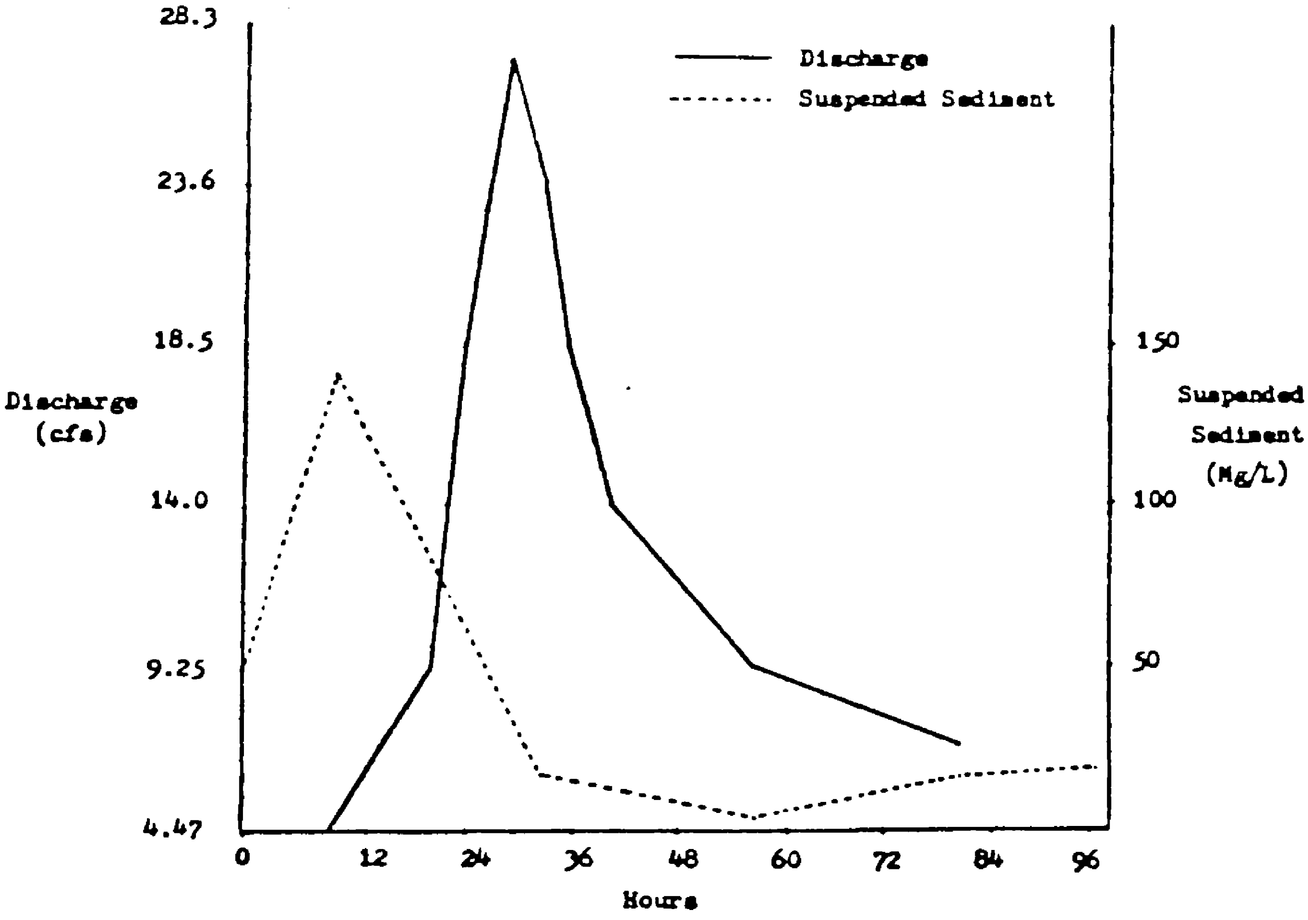
Comparison of Annual Precipitation for the North Fork of Elk Creek during the study period with the 25 year average recorded at Greenough, Montana.



headwater region give the North Fork a quick response to storm events. The hydrograph of a summer storm illustrates this point (Figure 5). In contrast, spring runoff is characterized as a gradual rising limb with slight fluctuations attributed to the freezing and thawing cycle common during that period. Peak spring discharges for the 1982-83 water year

FIGURE 5

Summer Storm Hydrograph for Drainage A.



were distributed over a two week period at the end of May (Figure 6, 7, and 8). Snowmelt in all three sub-drainages coincided fairly well. Inferences drawn from this point to a fairly equal distribution of of aspects among the catchments. Heavily timbered side slopes aid in snowpack retention and snowmelt synchronization (Gray 1981). Coincidence of spring rains with snowmelt hastens snowpack degradation and enhances runoff.

Rapid movement of subsurface flow is primarily a function of slope. Side slope gradients within the North Fork generally increase as the headwaters or divide boundaries are approached. Slopes range between 10 percent in the lower reaches to 60 percent in the steeper headwaters (Poliquin 1967).

Catchment drainage efficiency is dependent on the area encompassed and its underlying lithology (Wisler and Brater 1959, Megahan 1973). These attributes are reflected in the formation of drainage patterns, drainage density and stream frequency. Evolution of these characteristics is the result of continual erosion and the uniformity of the lithology (Hewlett and Nutter 1969). The granitics of the Garnet Stock have produced a dendritic drainage pattern with moderate drainage densities and stream frequencies (Table 1). Catchment shape is also noted as a factor in the concentration of stormflow and runoff (Lee 1980, Ward 1975, Wisler and Brater 1959). Snyder (as cited by Wisler and Brater 1959) has related stream distance from the geographical center of the basin to the mouth as a critical factor influencing stream discharge rates. In a similar sense, the compactness coefficent relates

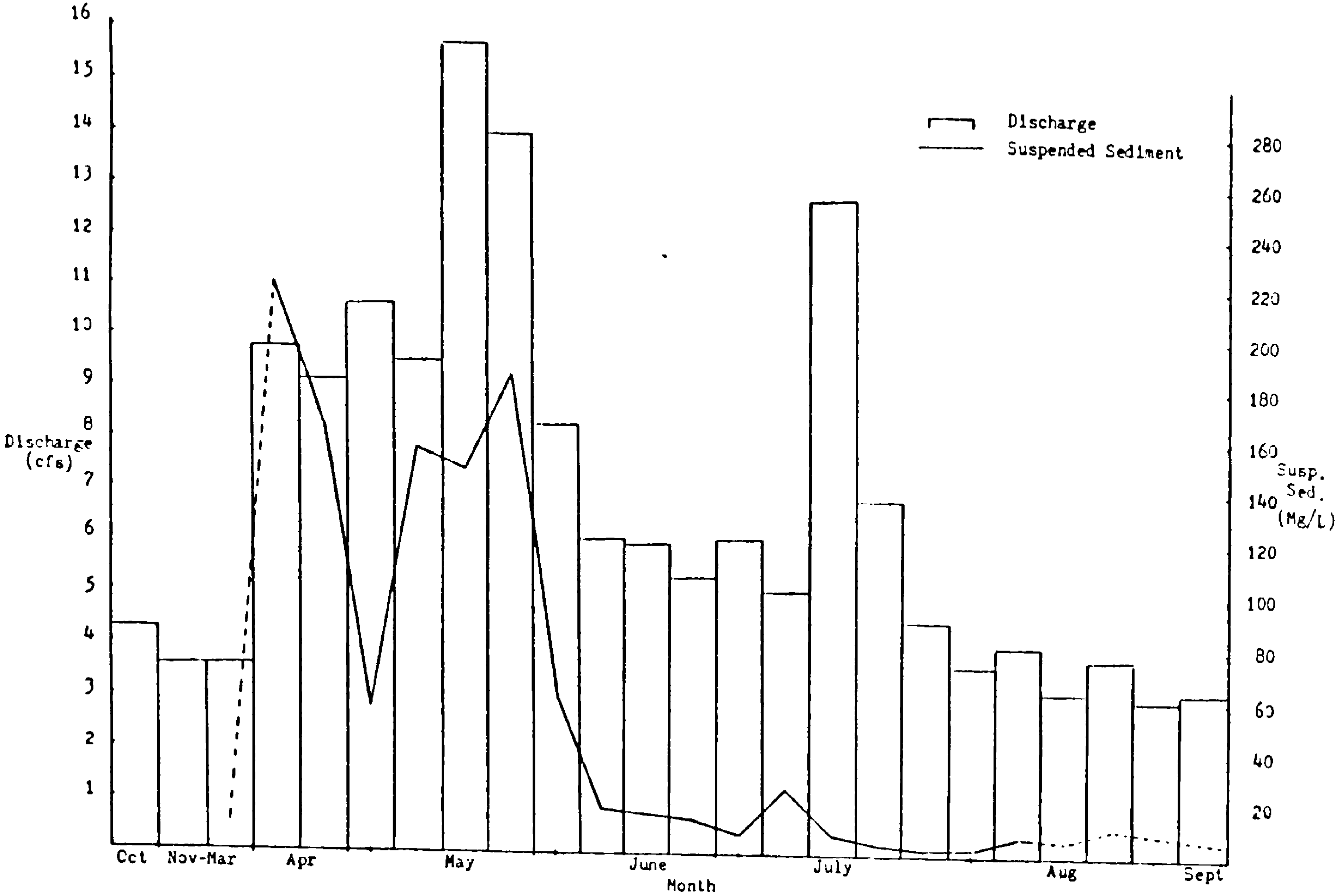


FIGURE 6

Weekly Discharge and Suspended Sediment Means for Drainage A.

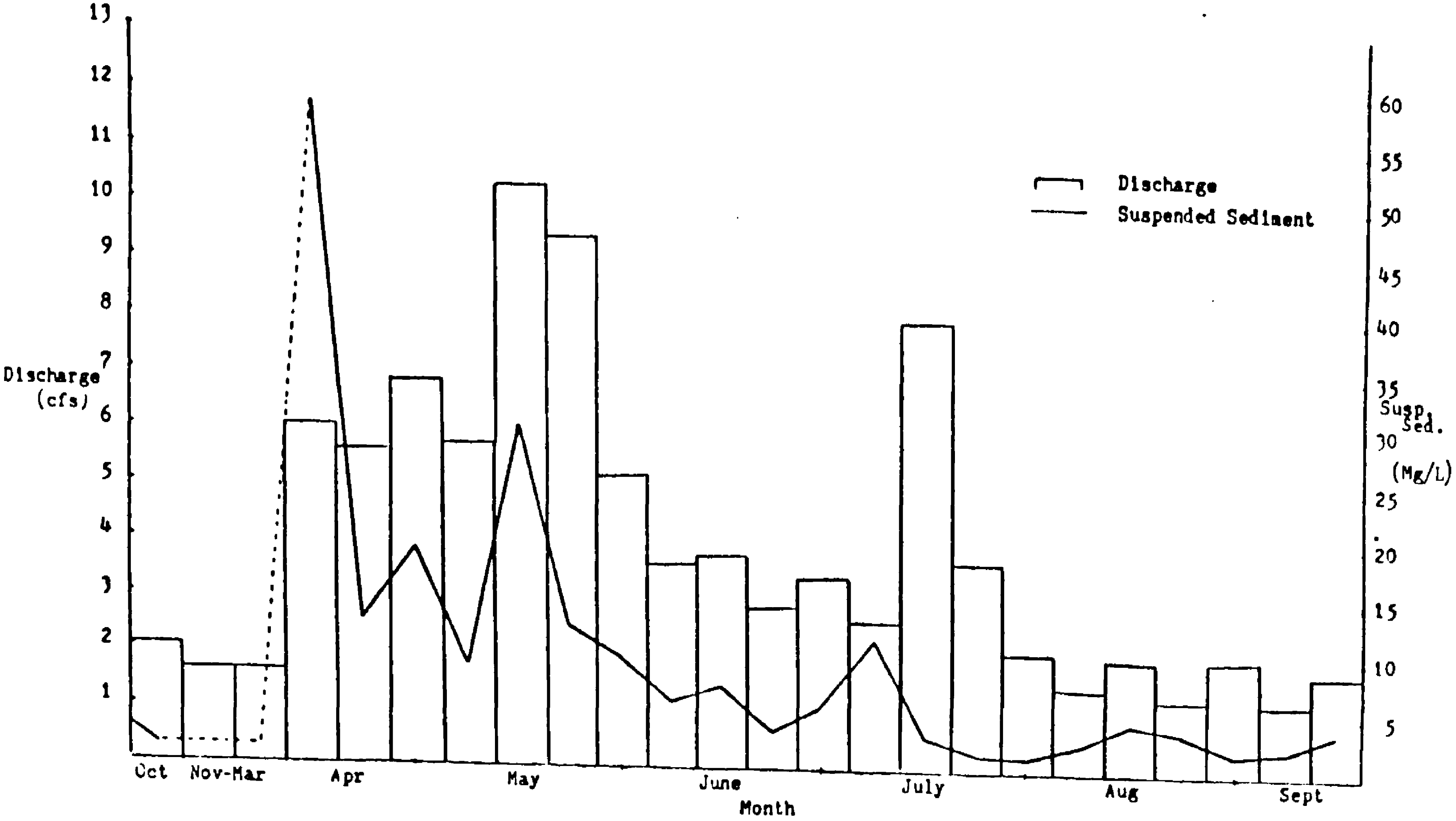


FIGURE 7

Weekly Discharge and Suspended Sediment Means for Drainage B.

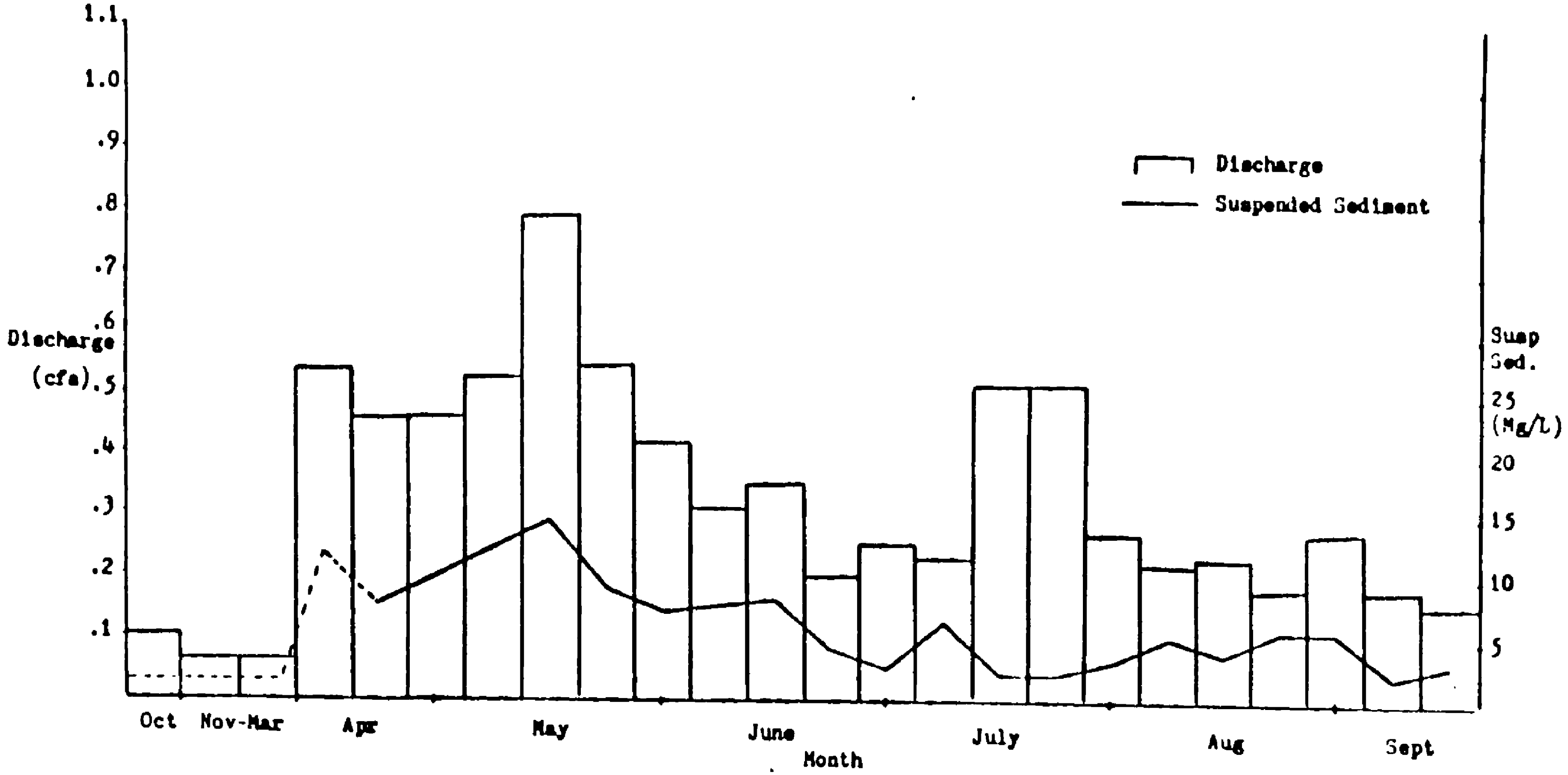


FIGURE 8

Weekly Discharge and Suspended Sediment Means for Drainage C.

basin perimeter shape to the circumference of a circle, which is considered the ideal shape for flow concentration (Gravelius 1914 as cited by Wisler and Brater). The North Fork is less than ideal in this sense. Its narrow elongated shape prevents optimum concentration of flow unless the storm is perfectly aligned with the watershed's central axis.

TABLE 1

DESCRIPTIVE MORPHOMETRIC STATISTICS FOR
THE NORTH FORK OF ELK CREEK

	Drainages		
Parameter	A	B	C
Area (Km^2)	17.15	10.84	3.04
(Mi^2)	6.62	4.18	1.17
Relief (m)	799	741	439
(ft)	2621	2431	1440
Min.(ft.)	1265 (4150)	1323 (4340)	1323 (4340)
Max.(ft.)	2063 (6768)	2063 (6768)	1762 (5781)
Basic Length (Km)	8.18	6.57	2.37
(Mi)	5.0	4.0	1.47
Stream Segments by Order 1	22	13	4
2	5	3	1
3	2	1	-
Total Stream Length (Km)	32.51	20.62	5.34
(Mi)	20.19	12.8	3.31
Stream Channel Gradient (m/Km)	69.7	86.3	105.7
(ft/mi)	368	456	558
Drainage Density	1.89	1.9	1.75
Constant of Channel Maintenance (ft^2/ft)	1732	1725	1862

Watershed orientation in relation to prevailing storm tracks directly affects precipitation distribution. Basins aligned with storm tracks in such a manner so as to receive uniform distribution or to have the storms moving upstream through the catchment show a gradual rising limb on the hydrograph. This is explained by intermittant contributions of tributary runoff to the main stream in such a way as to allow a steady release of runoff from the system. Basins receiving precipitation only over a localized portion or from the head of the drainage downstream tend to concentrate tributary runoff coincidentally in main channels resulting in more abrupt peaks (Ward 1975).

Temporal distribution of precipitation events is as important as spatial distribution. Difficulties quite often arise due to the highly autocorrelated nature of hydrologic events (Haan 1977). The occurrence of a series of hydrologic events can lead to substantial peak runoff periods. The North Fork experienced such a sequence of events in early July. Streamflow at this particular time of the year is still above baseflow levels due to recharge supplied by snowmelt. Soil storage capacities are often satisfied so any precipitation occurring generally produces runoff via accelerated interflow (under saturated conditions). Discharges recorded as a result of this early summer storm exceeded spring peak discharges by 33% (27 cfs vs. 18 cfs). Overland flow resulting from this event was apparent only along old roads. One parallels the main channel for about 3.4 km. and the other traverses the northern divide. These roads are about 20 years old and receive enough use that they are still actively eroding.

Basin elevation and topographic divides influence the type and amount of precipitation received. Temperature regimes associated with basins in high elevations may dictate a larger percentage of annual precipitation in the form of snow. This may be beneficial as an extended melting period could supplement soil storage and baseflow through the drier summer months. Elevated head walls and divides can offer orographic impedence to prevailing storms. As cloud banks rise to clear the obstruction, adiabatic cooling and condensation occur resulting in greater precipitation in high elevation zones. Mountain hydrology maps created by the SCS are based on this principle. For an area such as the North Fork, elevational differences account for about 12 additional centimeters in annual precipitation between headwater divides and the mouth (SCS Mtn. precipitation map). A hypsometric analysis shows that about a third of the drainage lies above 1700 m. (see Figure 2).

SUSPENDED SEDIMENT - DISCHARGE RELATIONSHIPS

Equipment Installation and Methods

The North Fork becomes a third order drainage about 2 km. from the mouth of the basin (Figure 9). Discharge monitoring and suspended sediment sampling sites were located just above the junction of the two second order stream segments (Drainages B and C). Gauging stations A and B were previously equipped with Parshall flumes (a 122 cm. and 152 cm. respectively). Drainage C was fitted with an 81 cm. H-flume in September of 1981. Each station was then equipped with Manning F-3000

Flowmeters and F-4040 Discrete Samplers. Power for these devices was supplied by a 12 volt battery at each site.

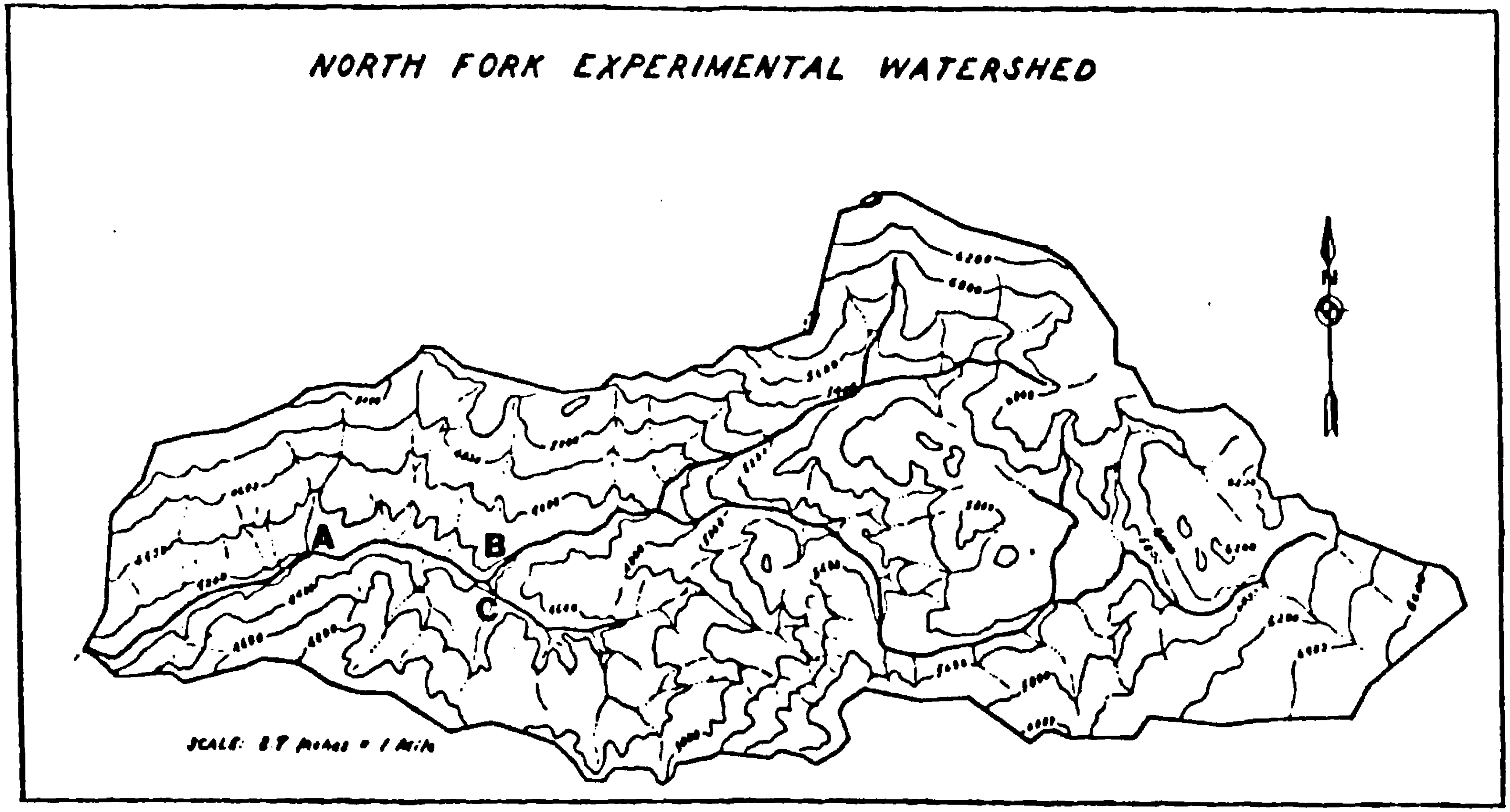
Manning F-3000 Flowmeters are capable of continuous monitoring of stream stage height. This is accomplished by a small probe being lowered every 5 seconds to touch the water and complete an electrical ground. The probe continually tracks stage height fluctuations translating this information through a special cam onto a chart as percentages of a precalibrated total stage height. The special cam within the Flowmeter is calibrated to match the flume configuration being used. A thirty day clock is available but charts were changed every two weeks during the study period.

The Manning F-4040 Discrete Samplers utilized in this study are capable of sampling at intervals ranging from 3 minutes to 24 hours. Maximum sample valumes are 500 ml. The number of samples taken per sample bottle can also be manipulated or multiple sample bottles can be filled at each sampling interval.

Two sampling schedules were maintained during the study. The first began in early spring and continued through peak runoff. This schedule consisted of drawing a 160 ml. water sample every four hours resulting in an integrated daily sample of 1000 ml. This procedure was more representative of actual water quality conditions than if a single point sample were to be taken for the same time.

FIGURE 9

Locations of Guaging Stations within the North Fork of Elk Creek.



The second sampling regime began after the high flows of spring had receded and base flow was once again the principle flow component. Samples during this period were collected every 6 hours with one sample bottle being filled every 24 hours. Initially there was some question as to whether the 6 hour sampling frequency was short enough to catch mid and late summer storm events. After analysing the data it was apparent that this interval was frequent enough to correlate increased sediment concentrations with the rising limb of the hydrograph associated with these storms (see Figure 4).

Determination of the above sampling regimes were based on the following criteria: equipment limitations, time availability for sample collection, equipment maintenance and lab analysis.

Sample bottles were collected for analysis bi-weekly during the spring and once a week for the remainder of the year. Samples were transported to the University where analysis for total suspended solids was completed. The American Public Health Associations Standard Methods for Examination of Water and Wastewater (1980) were followed in the determination of suspended sediment content of each sample.

Data Analysis

Normality of data is one of the assumptions governing statistical parametric analysis. In theory, a normal distribution encompasses both positive and negative values. In dealing with hydrologic phenomenon a [illegible] negative value is never encountered. Sample distributions are always positive and often skewed in appearance. Efforts to normalize data often include the use of transformations. Hydrologic phenomenon, in most cases, respond to log transformations (Chow 1964, Ponce 1980). Discharge and suspended sediment frequency distributions were compared to a normal distribution through utilization of the Kolmogrov-Smirnov Goodness of Fit Test (Sokal and Rohlf 1981) and graphical comparisons (Ponce 1980). Log transformations performed on the data yielded satisfactory approximations of normal distributions.

Discharge and sediment concentration data were broken into a spring interval and an annual interval. Nonhomogeneity of variance was determined by maximum F-tests (Ponce 1981) and Barletts Test (Snedecor and Cochran 1980).

Discharge-sediment data were then standardized, by dividing by respective drainage areas (mi^2). Individual two sample t-tests were used to compare both interval means between drainages for both variables.

Sediment rating curves were calculated for each drainage for Spring and Annual Intervals. Prediction equations were produced by regressing suspended sediment concentrations as a function discharge for the same time period. The resultant equations were then tested for parallel slopes and coincident intercepts utilizing large sample Z-tests (Kleinbaum and Kupper 1978). Comparisons were made between drainages (Annual vs. Annual, Spring vs. Spring).

Results and Discussion

Daily discharges within the North Fork are dominated by 3 flow regimes throughout the year. The first corresponds to the melting of winter and early spring snows. This period has the largest impact on discharge and sediment transport. Peak spring discharge rates and minimum annual rates are shown in Table 2. Values for Drainage A were about 10 cfs lower than those recorded by Poliquin (1967). This is a good example of the variability that is inherent within small

Table 2

Maximum and minimum discharge rates** for North Fork Drainages

Drainage		Month							
		Oct	Nov-Mar	Apr	May	Jun	Jul	Aug	Sep
A	Max	4.88	*	12.45	18.19	8.61	27.57	5.59	3.87
	Min	3.84	*	7.66	8.30	4.27	3.57	2.74	2.68
B	Max	2.55	*	8.39	13.22	5.84	20.85	3.79	3.45
	Min	1.78	*	4.32	5.08	2.03	1.65	0.95	1.17
C	Max	0.22	*	0.66	0.99	0.68	1.22	0.52	0.21
	Min	0.03	*	0.33	0.33	0.16	0.21	0.16	0.13

*Values unavailable due to freeze up.
**Discharge rates are in cubic feet per second.

mountainous watersheds (Beschta 1978). Figures 6, 7, and 8 depict discharge as it was as it was actually recorded for the duration of the study period at each site. Table 3 summarizes monthly distribution of annual discharge.

Table 3

<u>Total stream discharge for study period</u>
(Based on mean daily discharge rates)

		Month								Annual
Drainage		Oct	Nov-Mar	Apr	May	Jun	Jul	Aug	Sep	Total
	cfs	81.2	*	282.4	376.3	182.7	217.3	110.7	94.6	1345.3
A	ac-ft	161.1	*	565.2	745.1	361.7	429.6	219.2	187.4	2663.7
	%	6.0	*	21.2	27.9	13.5	16.1	8.2	7.0	
	cfs	74.4	*	174.4	242.8	97.0	122.2	48.6	56.8	816.0
B	ac-ft	174.6	*	344.6	480.7	192.1	241.9	96.2	112.6	1618.9
	%	9.1	*	21.3	29.7	11.8	14.9	5.9	6.9	
	cfs	3.9	*	11.8	17.7	9.0	11.6	6.9	5.1	66.1
C	ac-ft	7.7	*	23.3	35.1	17.8	22.9	13.6	10.2	131.2
	%	5.9	*	17.8	26.8	13.6	17.5	10.4	7.8	

*Values unavailable due to freeze up.

Mean daily discharge at each of the gauging stations was regressed against discharge at the other stations (Table 4). The simple linear models resulting indicated a good linear relationship between the drainages. The strongest, as was expected, was between drainages A and B. Drainage B encompasses 63 percent of the main drainage A and as such, it should be very strongly related with A's discharge.

Table 4

Mean daily discharge for each drainage regressed against discharge of other drainages ($H_o : \beta = 0$)

Dependent (Y)	Independent (X)	a	b	r	n	SEE	Significance (α = .05)
Q_A	Q_B	1.43	1.35	.98	143	.68	**
Q_A	Q_C	0.74	17.2	.85	141	2.1	**
Q_B	Q_C	.012	11.5	.86	195	1.3	**

Equation format: Y = aX
Q = Discharge in cfs

*Non-significant
**Significant

The second flow regime is baseflow. Baseflow from mountain drainages can be comprised of almost entirely unsaturated lateral flow (Hewlett and Hibbert 1963). Recharge from spring snowmelt and early summer storns help sustain baseflow through summer. Precipitation events occurring further upslope have been shown to contribute more to baseflow by temporary soil storage than to direct runoff (Ward 1975). Baseflow discharge rates can be seen in Table 2. Poliquin (1967) noted several springs in the northeast headwater area as supplemental discharge areas that seem to sustain baseflow for Drainages A and B. Drainage C with a minimum recorded discharge rate of .03 cfs appears to be at the mercy of quickly depleted soil and bank storage. Shallow soils derived from granite have poor water retention capabilities. Soil water depletion is further accelerated by vegetative consumption and rapid subsurface drainage.

Storm flow is the final flow regime. The North Fork reacts differently to storm runoff depending on the season. Early spring storms often supplement snowmelt water in soil storage recharge. The impact of these storms is somewhat lessened by the fact that soil demands must be met prior to excess water being freed. Peaks during this period will tend to be subdued. Storms occurring during late spring show effects that are more readily apparent as they are operating under a saturated soil conditions. Response to these storms is generally quick and short-lived. Mid and late summer storm reactions depend on the intensity and duration of the event and the progression of soil water depletion. The storm occurring in early July (see Figure 5) caused the stream to react similarly to the second situation described above. Precipitation received during this event was 5.6 cm. If projected over the whole drainage this one event provided 775 ac-ft of additional recharge.

Comparisons of Spring and Annual Discharge and Suspended Sediment Concentrations

Spring discharge accounts for 58 to 62 percent of annual discharge for the three study basins (Table 5). This corresponds to the findings of other researchers who observed that sediment concentrations were a function of stream discharge when availability was not a limiting factor (Anderson 1954, Branson et al. 1981, Porterfield 1972, Leaf 1966). From 17 to 58 percent of the variation associated with suspended sediment concentrations was explained by discharge (Table 6). Spring

Table 5

Seasonal distribution of discharge and suspended sediment concentrations

Drainage	Spring(Apr-Jun)		Summer(July-Sept)		Annual	
	Q*	Sed*	Q*	Sed*	Q (ac-ft)	Sed (ton/mi^2/yr)
A	62.6	9.0 ?	31.3	3.0	2663	26.70
B	62.7	89.6	27.7	10.4	1618	4.65
C	58.0	73.6	35.7	26.4	131	0.72

*Values represent percent(%) of total

discharges-suspended sediment concentrations showed the highest correlations for all three drainages. This seems appropriate as this is the period of highest sustained runoff with many instantaneous peaks being common. Water temperature at this time of year may also play a role by increasing carrying capacity (Heede 1980). Sediment concentrations appear to be more variable than discharge rates. This point is illustrated by Figure 4 and has been documented before (Porterfield 1972, Beschta 1978).

Examination of Tables 7 and 8 shows that comparions between drainages for both spring and annual intervals were significantly different, except in 2 cases. Both instances occurred during the spring. Failure of standardized discharge means for Catchments A and B to show a significant difference can be explained again by the percentage of A comprised by B (64%). Standardizing both by dividing by prospective drainage areas may have reduced noticeable differences

TABLE 6

DISCHARGE - SUSPENDED SEDIMENT REGRESSION EQUATIONS

Spring	Dependent (y)	Independent (x)	n	r^2	SEE
Drainage A	Susp.Sediment	Discharge	63	.58	.37
Drainage B	Susp.Sediment	Discharge	63	.37	.33
Drainage C	Susp.Sediment	Discharge	58	.26	.26
Annual					
Drainage A	Susp.Sediment	Discharge	99	.48	.54
Drainage B	Susp.Sediment	Discharge	165	.35	.45
Drainage C	Susp.Sediment	Discharge	161	.17	.32

General form of Regression Equations $Y=ax^b$

between the two, particularly in light of the fact that between these two gauging stations there are no other major tributaries contributing to the main stem. In fact only 10.96 ac-ft. separate both discharge regimes after standardization for the spring interval.

The second case shows a similarity between sediment concentration for Catchments A and C. This failure to show significant differences is a bit more perplexing. It was assumed prior to the comparison that Drainage A would naturally show sediment concentrations significantly different from both B and C. This assumption was based on drainage A encompassing a larger area, an area more conducive to the addition of sediment from channel and upslope processes and by virtue of its greater discharge rate. Explanation of this similarity may lie in the physical

TABLE 7

T-TEST FOR EQUALITY OF MEANS
(DISCHARGE AND SUSPEND SEDIMENT CONC.)
BETWEEN DRAINAGES (SPRING MEANS)

Variable	Drainage	n	df	T value	Significance (=.01)
	A vs. B	71	70	1.03	NS
Discharge	A vs. C	69	68	36.6	S
	B vs. C	67	66	27.17	S
	A vs. B	59	58	7.8	S
Suspended Sediment Conc.	A vs. C	54	53	-.05	NS
	B vs. C	57	56	-10.7	S

TABLE 8

T-TEST FOR EQUALITY OF MEANS
(DISCHARGE AND SUSPENDED SEDIMENT CONC.)
BETWEEN DRAINAGES (ANNUAL MEANS)

this is the critical value of t for significance α = .01

Variable	Drainage	n	df	T value	Significance (=.01)
	A vs. B	143	142	2.57	S
Discharge	A vs. C	141	140	2.57	S
	B vs. C	195	194	2.57	S
	A vs. B	100	99	2.57	S
Suspended Sediment Conc.	A vs. C	95	94	2.57	S
	B vs. C	142	141	2.57	S

characteristics promoting the erosion process and its subsequent transport. Channel gradients and proximity to the erosion sites could account for the similarity. Drainage C has a greater stream gradient per square kilometer than does A (Table 1). At times of high discharge it could possess a greater potential for erosion. The increased velocity associated with a steep gradient also enhances stream capacity (Morisawa 1968), guaranteeing a higher delivery rate. Heede's (1980) concept of a stream gradient equilibrium may also shed some light on this result. Youthful streams promote steep gradients and accelerated headward erosion, while mature streams are characterized by more gradual gradients and a decrease in headward erosion. Armouring of stream channel is also more likely in a mature stream. In light of Drainage C's steep channel gradient and short basin length it is likely that actively eroded material within the stream and introduced from hillslope processes will show up at the critical reach during periods of high discharge. The opportunity for sediment storage with Drainage A prior to the critical reach is greater as basin length increases and gradient decreases (Strahler 1964, Branson et al. 1981). Thus, similar means for sediment concentrations during sustained high discharge periods could be reasonable. Both catchments are underlain by the same granitic stock and presumably have the same natural erosion rates.

Sediment Rating Curves

A sediment rating curve consists of a graph or equation, relating sediment concentration to discharge (Walling 1977). This curve can then be used to estimate sediment loads based on stream flow records.

Rating curves were originally developed for use in describing sediment-discharge relationships for large rivers where daily estimates of sediment concentrations are available and accurate. Rivers often show a slow response as a result of storm events making it possible for sampling during all stages of the hydrograph. Streams draining medium and small mountain catchments are much more rapid in their response to storms both in discharge and induced sediment concentrations. This creates sampling problems in defining accurate relationships. Thus, the development and implementation of rating curves helped resolve this problem by shortening the time needed for sampling in order to define a relationship between suspended sediment and discharge. Errors associated with rating curves based on average daily rates and concentrations have been estimated at a low of 5 percent and a high many magnitudes greater (Walling 1977). This variability has been attributed to sampling techniques, lab procedures, unreliable flow data and the inability to dequately define the detailed temporal record of suspended sediment concentrations. Other inaccuracies of rating curves can be due to the nature of the catchment, the time interval of the event being sampled and the procedures being used to develop curves (Porterfield 1972).

Inferences can be drawn about drainages based on the shape of the rating curves they yield. Steep sloped curves are indicative of streams with high sediment transport rates. These streams have high sediment availability and are generally enclosed by banks showing fair to poor stability (Rosgen 1975). Channel erosion can contribute substantially to yields from watersheds if the underlying strata is of unconsolidated origin (Anderson 1954). This is especially true when more than 50 percent of annual discharge comes during a three month period. Streams situated on more resistant material reflect a flatter curve. These streams show good bank stability and recover quickly from introduced sediment (Rosgen 1975).

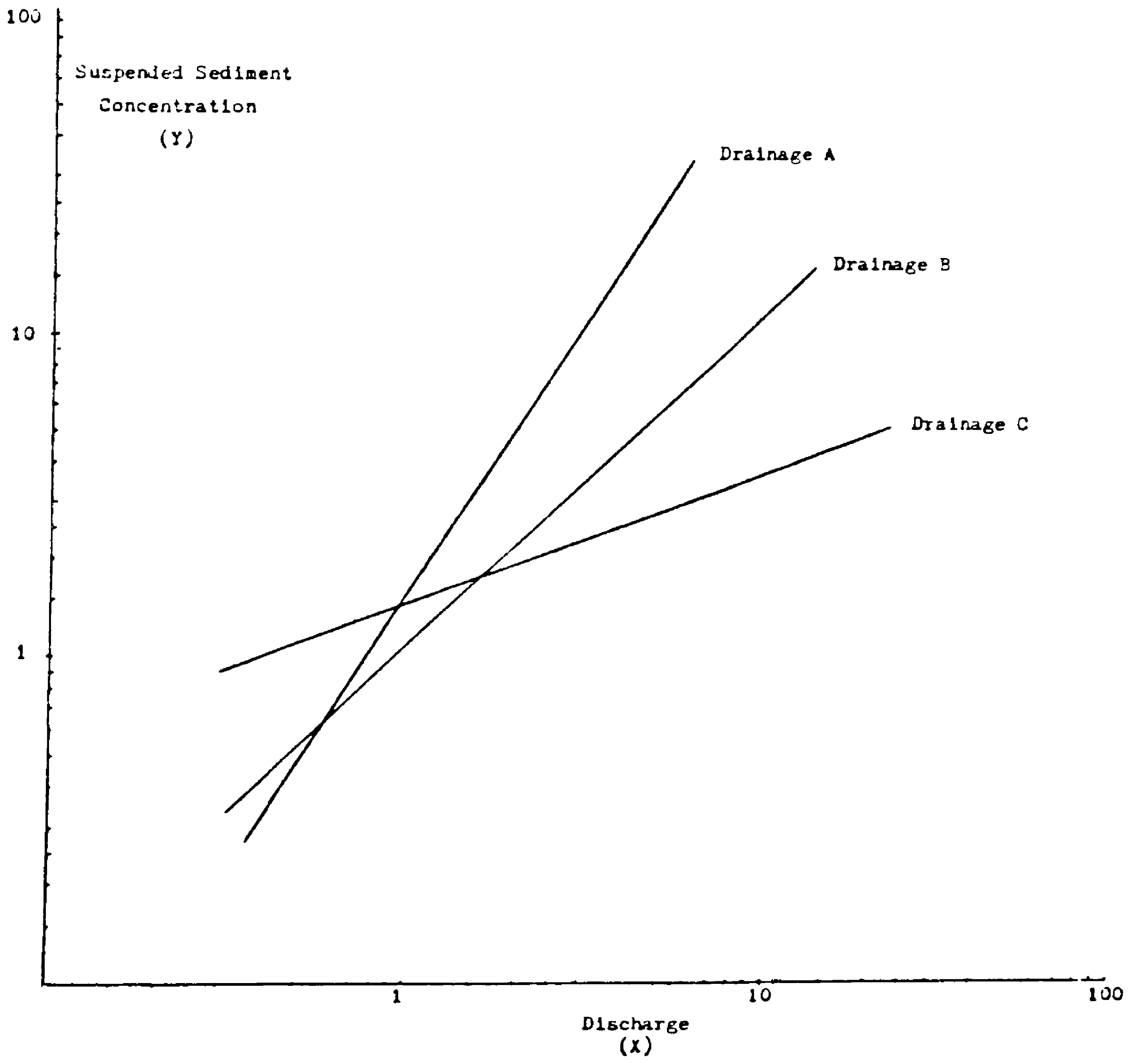


FIGURE 10

Mean Daily Suspended Sediment Rating Curves

Development of seasonal rating curves has been suggested as a more accurate method of delineating sediment discharge estimates (Beschta

1978, Walling 1977). This would be more appropriate for areas showing two or more distinct peak flow regimes. McPherson (1975) found no evidence to indicate the need for separate seasonal rating curves in his Alberta study.

TABLE 9

EQUATIONS FOR SUSPENDED SEDIMENT RATING CURVES
FOR TWO TIME PERIODS (Spring, Annual)
WITHIN EACH DRAINAGE

Drainage	Time Interval	Dependent (y)	Independent (x)	a	b	n	r^2	SEE	Sig.
A	Spring	Susp.Sed.	Q	-.873	2.72	63	.58	.372	NS
	Annual	Susp.Sed.	Q	-1.09	2.71	99	.48	.545	
B	Spring	Susp.Sed.	Q	.017	1.3	63	.37	.331	NS
	Annual	Susp.Sed.	Q	- .04	1.14	165	.35	.457	
C	Spring	Susp.Sed.	Q	1.18	.85	58	.26	.259	NS
	Annual	Susp.Sed.	Q	.914	.54	161	.17	.325	

Equation Format $Y=aQ^b$, Where Q=discharge, Y=Susp.Sediment Conc.

Mean daily suspended sediment rating curves developed for this study (Table 9) do not show a significant difference between spring and annual intervals. Comparison of slopes between the individual curves showed significant differences. Drainage C produced the flattest slope coincident with the lowest sediment yield (.72 tons/mi^2/yr) (Figure 10). Based on these results it would appear that C may be the most stable drainage of the three. A deeply incised channel coupled with well-vegetated steep side slopes has reduced the opportunity of fluvial deposition and restricted the amount of unconsolidated material that is easily eroded and transported. Drainages A and B, in contrast, occupy larger valleys which have accumulated greater alluvial deposition especially in the middle and lower reaches of the main stem. Larger catchment areas contributing greater discharge must also be considered a factor.

Sediment discharge rating equations demonstrate only a fair r-squared (Table 9). This is to be expected as the duration of the study was too short to account for much of the variability in such a fluctuating natural system. Explained variability in the discharge sediment relationships was highest for Drainage A and lowest for C. Suspended sediment availability may also be an influence effecting these relationships.

Actual Sediment Yields

Two estimates of sediment yields were derived from mean daily discharge rates and corresponding sediment concentrations (Table 10). The first was calculated directly from data obtained during the monitoring period. The second are estimated yields calculated from equations developed to describe the discharge-sediment relationship within catchments. Values were calculated for annual intervals. Comparion of actual and estimated values show that the derived yields are much closer to the actual than had been anticipated. When examining model statistics, as mentioned before, discharge does not account for much of the variation in sediment concentrations (see Table 9).

Table 10

Actual and estimated suspended sediment yields*

Drainage	Time Interval	Actual Value	Estimated Value
A	Annual	26.7	30.0
B	Annual	4.65	3.58
C	Annual	0.72	0.62

*Tons/mi^2

The most abrupt differences illustrated by these results are between drainage values. Drainage A produces 5 times more sediment than B and 37 times more than C. Explanation of this may lie in the stretch of channel between the junction of streams B and C and the gauging station A. This particular reach of stream is paralleled, sometimes very closely, by a dirt access road. This road is the only site within the catchment where observed overland flow has occurred and is actually channeled down wheel ruts. These ruts, functioning as runoff collectors, overflow at several points emptying directly into the stream. Point sources such as these have been shown to increase sediment yield within streams up to 4 times the natural load (Megahan 1972). This lower reach is also the widest portion of the drainage. Well logs from a previous study (Poliquin 1967) have shown that alluvial desposits in this area can be 15 to 20 feet deep. Streams entrenched in unconsolidated material will generate more channel erosion as deposition bars and thalwegs begin to develop (Anderson 1954, Rosgen 1975). The

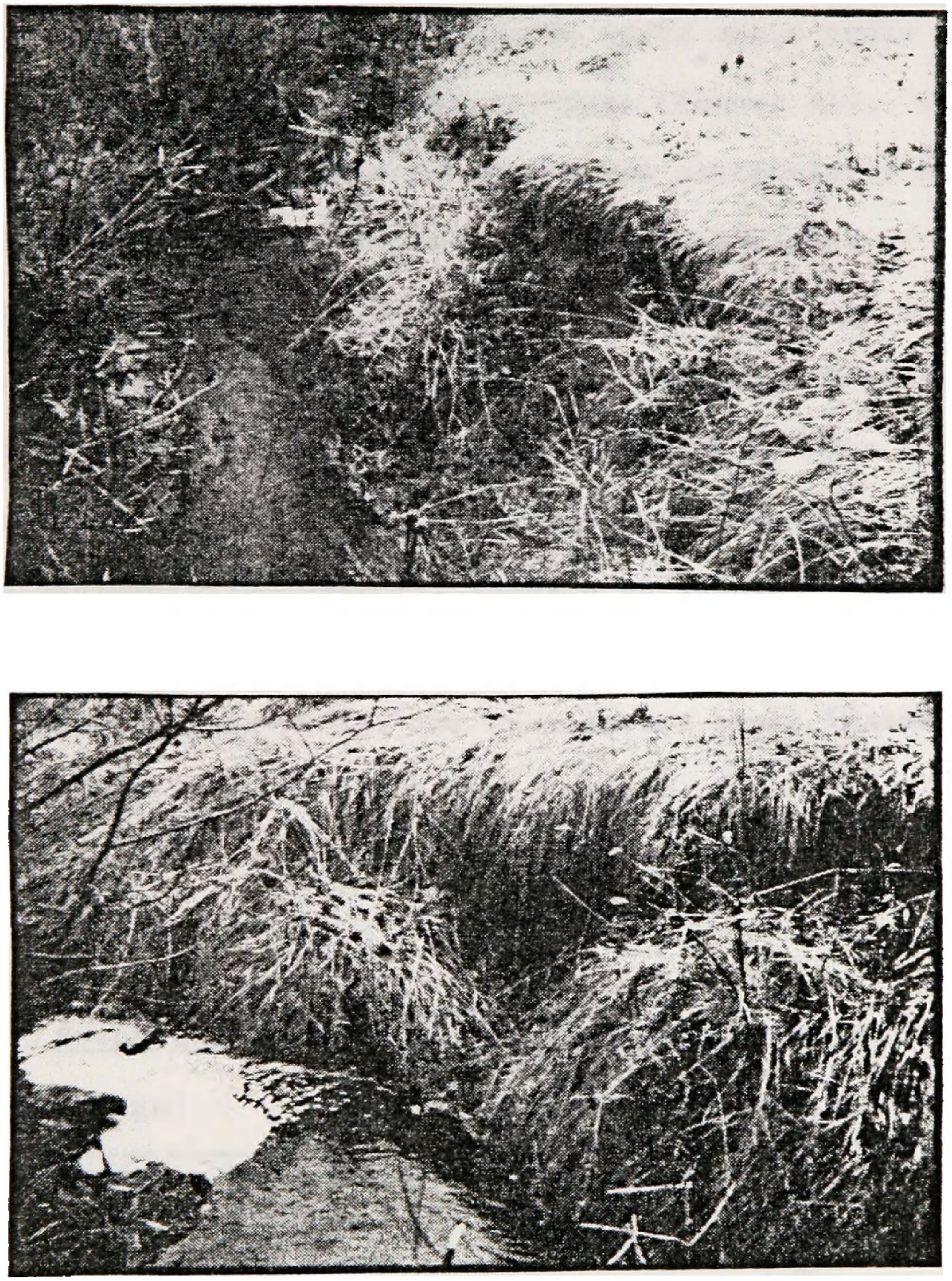


FIGURE II

Examples of stream bank
instability along Drainage A.

primary reason may be caused by lack of bank stability. The lower stretch of the main stem shows numerous spots where banks have been undercut and are in some stage of collapse (Figure 11). These areas can add substantially to the load of the stream particularly during peak flow periods when carrying capacity of the streams are at their highest. In essence, these areas of instability are analogous to mass failures but on a much smaller scale. Thus, it is felt that Drainage A does not truly represent a natural undisturbed catchment despite the fact that the yields generated compared very nicely with Megahan's (1972) "normal" watershed sedimentation rate for Idaho's undisturbed granitic areas. Research in the Bitterroots support this opinion as sediment yields have averaged about 12 tons/mi^2/yr for undisturbed areas (Hammer 1983) (Table 11).

Table 11

Suspended sediment yields for granitic watersheds

Drainage	Suspended Load (tons/mi^2)
Bitterroot Watersheds	
Martin Creek	11.81
Meadow Creek	7.91
Moose Creek	5.81
Paint Creek	58.70
Tolan Creek	10.29
Warm Springs	6.61
Study Drainages	
A	26.70
B	4.65
C	0.72

Drainage C appears to be on the other end of the scale. This result could be a function more of sampler placement than actual basin production. The automatic sediment sampler is located next to the power source in an approachway to a 81 cm v-notched weir. This site, selected during a period of high flow, provided enough clearance for the intake hose to take a representative sample from the mid-point between the surface and the bottom without sucking in any extraneous bottom material. Behind the approach way is a small backwater or ponding area created when the cement foundation for the weir was installed. This small impoundment is large enough to induce sediment desposition prior to it reaching the sampling device during most of the intermediate and smaller peak flow periods. This bias may be enough to reduce concentrations being sampled and give the false impression that the catchment is yielding very small amounts of sediment. This is also the only site where samples are not drawn from a mixing zone within the stream.

Drainage B appears to be the most representative of the study basins for yielding naturally induced sediment. This drainage is an extension of the main stream and reaches up into the headwater region of the catchment. It is relatively unimpacted by any of man's activities and is buffered from any upslope erosion contributions, barring a large mass failure, by a thick riparian zone. The majority of the area it drains is characterized by heavily timbered side slopes, talus slides and granitic bedrock outcrops.

Predicted Sediment Yields

One attempt was made to predict naturally occurring sediment yields using a model developed by soil scientists, hydrologists, and watershed specialists of the Northern and Intermountain Regions of the U.S. Forest Service. This model, obtained from a document entitled "Guide for Predicting Sediment Yields from Forested Watersheds" (Cline, et al. 1981) simplifies, for purposes of analysis, a very complex natural system. This model uses stratified land systems inventory map units to estimate on-site erosion for a given management activity. Erosion generated sediment is then delivered to the stream based on land type characteristics and routed to a critical reach where it is hypothetically monitored. This model is also capable of simulating natural systems, again based on land type characteristics. For the entire North Fork an estimate of 13.5 tons/mi^2/yr was calculated. This value in comparison with actual values (Table 10) was low. It did approximate average annual yield somewhat more closely (16 tons/mi^2/yr vs. 13 tons/mi^2/yr).

CONCLUSION

Suspended sediment yields within the North Fork of Elk Creek varied considerably. Variability was attributed to differences in discharge rates, bank stability, consolidation of underlying substrata and road location. Poor correlations between sediment concentrations and discharge rates can also be accounted for by site variability. Hydrologists often attempt to strengthen this relationship by regressing sediment yield, instead of sediment concentrations, on discharge. The noted improvement is more of a statistical manipulation than anything else, as sediment yields are calculated using discharge values. The variability demonstrated by the North Fork is not uncommon for granitic watersheds (Hammer, pers. comm. 1983).

Actual suspended sediment yields generated by the watershed are comparable to Megahan's (1972) Idaho findings and fit well within the wide range of values determined for the Bitterroots.

CHAPTER 2

Testing of Regionalization Assumption

INTRODUCTION

One of the most difficult problems a forest hydrologist must deal with is the assessment of hydrologic impacts of management activities on ungauged streams. Speculation about natural conditions after the impacts occur is meaningless. Establishment of a link between geomorphic parameters and hydrologic output would make the prediction and assessment of management activities more precise.

A drainage basin can be assumed representative of a broad hydrologic region (Ebismiju 1979). Accurate delineation of these regions, because of the complexity of the system, must include descriptors from all contributing processes within the basin. Intercorrelation of basin parameters suggests that regional identities are the result of diverse combinations of differences. Thus, there is a need to combine linear, areal and relief attributes in any morphometric classification (Woodruff 1964). Yamamoto and Orr (1972) theorized that development on the same lithology, under similar climate and orientation, basins could be expected to be geomorphically similar regardless of size.

If a drainage basin is indeed an integrator of physical, biological and hydrologic processes within its boundaries, then the quantitative results of those processes (water and sediment yields) should be related to the morphology they originate from (Branson et al. 1981, Yamamoto and Orr 1972).

OBJECTIVES

The geomorphic characteristics of the North Fork of Elk Creek are examined and compared with other Montana watersheds by:

A. Classifying randomly chosen western Montana watersheds into hydrologic categories established by Potts (1983).

B. Determining the distribution of morphometric parameters within each group and transformations to normalize them, if necessary.

C. Testing for significant differences between the means of selected parameters between groups.

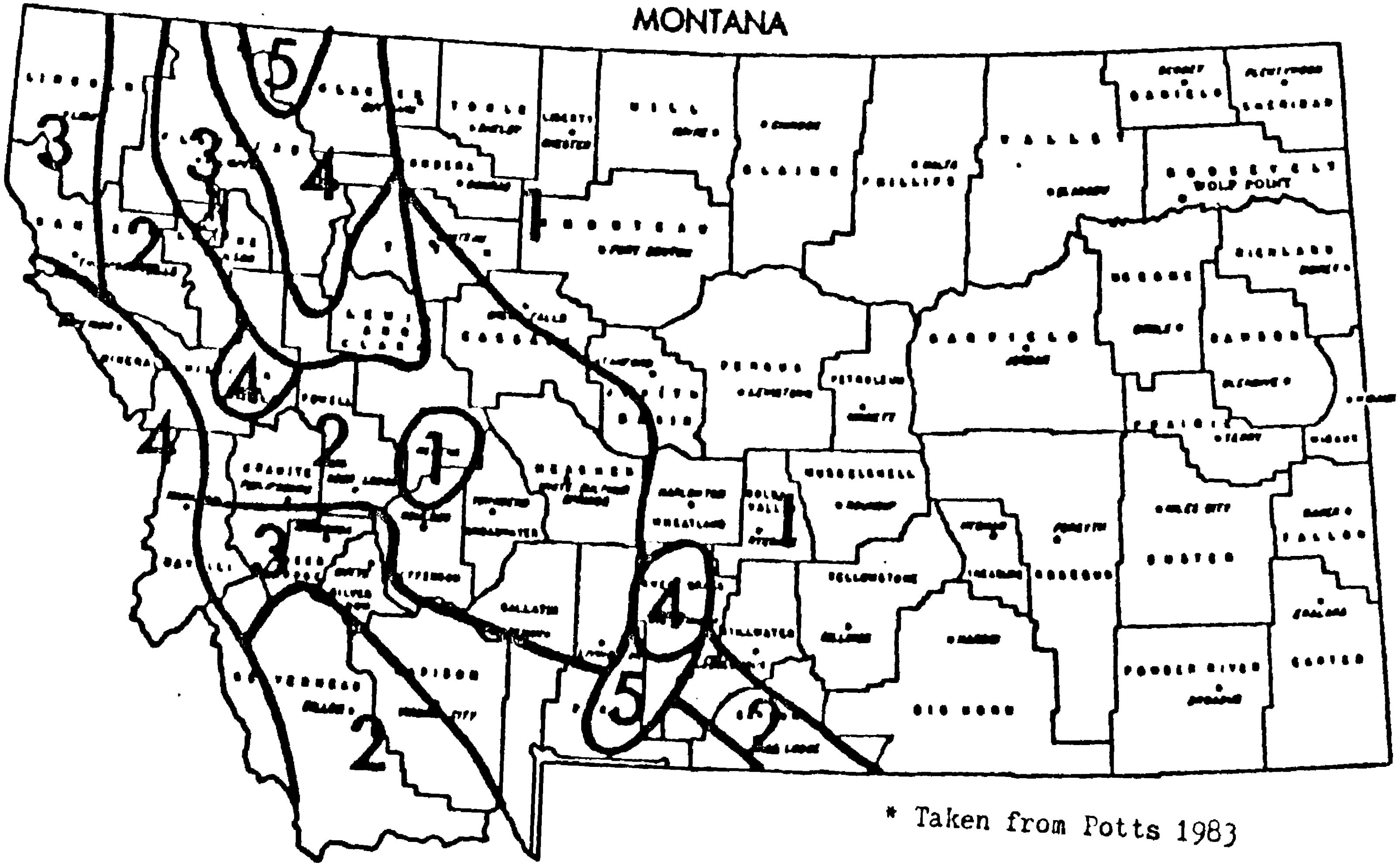
D. Comparing morphometric parameters of the North Fork of Elk Creek with parameters developed for groups of similar hydrologic classification.

METHODS AND STUDY DESIGN

Watershed Group Selection

An initial random selection of 102 watersheds in western Montana was made based on the U.S. Forest Service Northern Region Land Systems Inventory. This system is a series of hierarchical classifications delineated by: Province, areas of subcontinental similarities; Sections, divisions of Provinces demonstrating broad vegetation regions of uniform climate; and Subsections, the smallest land unit relating to geology, structure and geomorphic processes (USDA For. Serv. Northern Region 1975). Approximately 20 watersheds were selected in each of five of the most common subsections, one of which included the North Fork of Elk Creek. These subsection delineations were expected to be of fine enough resolution to reduce variation within groups and accentuate differences between groups. Scott (1983) discovered this was not the case. Thus, an alternative system of grouping had to be selected.

Boner and Buswell (1970) proposed a system of regionalization for Montana consisting of three hydrologic regions. Climatic variables and basin characteristics were utilized to identify and delineate these homogeneous regions. This study concluded that high model prediction errors were due to the inadequacy of refining climatic and basin characteristics, primarily geology and basin precipitation. Potts (1983) summarizes recent advances in refinement of these problem areas, particularily annual precipitation and describes two new regionalization models. Accurate predictions of average annual discharge and mean annual floods have enabled the division of Montana into 5 streamflow subgroups (Figure 12). These subgroups are the basis for grouping the watersheds in this study. Table 12 summarizes the number of watersheds associated with each group. Discrepancies between group sizes and omission of groups 1 and 5 can be attributed to the original selection procedure of the watersheds.



* Taken from Potts 1983

FIGURE 12

Division of Streamflow Regions within Montana.*

Table 12

Number of watersheds within each hydrologic group

	Group 2	Group 3	Group 4
Number of watersheds	17	59	34
Percent of total	15.4	53.6	30.9

Geomorphic Parameters

Five morphometric parameters were measured for 110 watersheds. U.S. Geological Survey maps (7.5′ Quad. Series) scaled 1:24,000 were used to locate watersheds and to measure parameters. This provided consistency during the measuring process reducing the error often inherent in taking measurements from maps of differing scales (Gardiner 1974). Parameters were selected for measurement based on previous research demonstrating applicability to projects of a similar nature (Ebismiju 1979, Yamamoto and Orr 1972, Gardiner 1974). Selected parameters and methods of calculation are summarized in Table 13.

Analysis

Data were tested for normality as it is quite common for morphometric parameters to be non-normally distributed (Gardiner 1974). Kolmogorov- Smirnov Goodness of Fit Tests (Sokal and Rolf 1981) were employed. Log transformation inproved approximations of normal distributions although in the case of stream frequency a square root transformation proved more appropriate.

TABLE 13

SELECTED GEOMORPHIC PARAMETERS

	Symbols		Measured or Calculated	Author Responsible for Method of Calculation & Definition	
	Abbrev.	Units			
Area [1]	A	Km^2	measured	Horton	1945
Relief [2]	H	m	measured	Strahler	1952
Total Stream Length [3]	S	m	measured	Horton	1945
Number of Stream Segments [4]	N	dimensionless	measured	Horton	1945
Relief Ratio	R	dimensionless	$R=H/L$	Schumm	1956
Elongation Ratio	E	dimensionless	$E=(\frac{2}{\pi^{.5}})(\frac{A^{.5}}{L})$	Schumm	1956
Drainage Density	D	Km	$D=S/A$	Horton	1945
Stream Frequency	F	Km	$F=N/A$	Horton	1945
Constant of Channel Maintenance	CCHM	Km	$CCHM=1/D$	Schumm	1956
Basin Length [5]	L	Km	measured	Horton	1945

[1] Area encompassed within basin divides.

[2] Difference between highest and lowest points in the basin.

[3] Total length of streams within the entire basin. This includes intermittent streams.

[4]. Total number of 1st, 2nd and 3rd order stream segments in basin.

[5]. A line from basin mouth to a point on the perimeter equidistant from the mouth in both directions.

Discriminant analysis was utilized to see if chosen parameters accurately classified each watershed into its predetermined streamflow grouping. This was a test to determine the validity of the alternative grouping scheme suggested by Potts (1983) and reflected in geomorphic characteristics inherent to watersheds within each region.

Inter-group means for each parameter were compared for significant differences by t-tests (Snedecor and Cochran 1980). Results of these comparisons will illustrate where overlap occurs between different groups yielding insight into future parameter selection.

The final analysis was to determine if the morphometric features of the North Fork approximated those of other similarily classified watersheds. T-tests were utilized to detect differences between the group mean for each parameter and its counterparts in the North Fork drainages.

The analyses described above were processed using SPSS and BMDP statistical packages.

RESULTS AND DISCUSSION

Discriminant Analysis of Streamflow Grouping

The objective of discriminant analysis is to weight and linearly combine discriminating variables in such a manner that groups are as statistically separate as possible (Kleeka 1975). Tasker (1981) used this technique to classify ungauged watersheds by flow regime using basin characteristics. In a similar study Waylin and Woo (1981) separated basins into flood regions by incorporating discriminant analysis and estimated Gumbel parameters (extreme event occurances).

Table 14

Summary of group placements vs. predicted group placements

Actual Group	Number of Cases	Predicted Group Membership 2	3	4
Group 2	17	7 (41.2%)	6 (35.3%)	4 (23.5%)
Group 3	59	5 (8.5%)	44 (74.6%)	10 (16.9%)
Group 4	34	4 (11.8%)	14 (41.2%)	16 (47.1%)

Percent of "grouped cases" correctly classified: 60.9%

In the present study, discriminant analysis was used to assign watersheds into three predetermined streamflow regions. Initial classification was based on the physical location of each catchment. Sixty-one percent of the watersheds were correctly classified into existing groups (Table 14). This is a distinct improvement over Scott's (1983) results using Land Systems subsections. Seven morphometric variables (area, relief, stream length, number of stream segments, relief ratio, drainage density, stream frequency) were used in the final analysis. Numerous combinations were calculated including Scott's (1983) four independent variables in an attempt to maximize accurate grouping percentages. Two patterns become apparent when examining Table 14. First, each group has a higher percentage of correctly classified watersheds then incorrectly classified. One other function of eight variables correctly classified a larger percentage of watersheds (63%). In doing so it failed to delineate between groups three and four, both contained 47% of the watersheds. Thus, this function was eliminated. The other pattern is that as the number of cases within each group increased, the percent of "grouped" cases correctly classified also seemed to increase. This may suggest that as the number of observations within the group increased, the group became more statistically distinct; more variability was accounted for.

Is it possible to improve on the percentage of accurately grouped watersheds by selection of different geomorphic parameters or a more accurate delineation of hydrologic regions? The morphometric parameters selected for this study, as mentioned before, were chosen based on ease of measurement and those shown to be valuable in past research. It is beyond the scope of this study to elaborate on the selection of other pertinent parameters. Gardiner (1974) does caution though, that care be taken in the selection as the interrelationships of geomorphic variables can lead to redundancy. The validity of the streamflow regions established by Potts (1983) could be checked through the combination of morphometric variables as demonstrated by this study, and hydrologic processes (average annual precipitation). The ensuing model could again be used to predict average annual discharge and re-establish streamflow regions that validate or invalidate current boundaries.

Comparison of Intergroup Means

The t-test comparison of intergroup means provided additional information about the morphometric parameters chosen (Tables 15 and 16). Four of the nine variables showed a significang difference between groups. Three of these variables (relief, drainage density, stream frequency) were included in the final discriminant functions. The constant of channel maintenance added insignificantly to these functions and was removed. This is understandable as its relationship to drainage density (cchm = 1/DD) prevented the inclusion of both.

TABLE 15

COMPARISON OF SAMPLE STATISTICS FOR
NINE WATERSHED CHARACTERISTICS BY GROUP

	Group 2		Group 3		Group 4	
Variable	Mean	STD.Dev	Mean	STD.Dev	Mean	STD.Dev
Area	5.91	4.38	4.95	2.56	4.25	3.17
Relief	695.53	160.39	716.2	187.27	723.53	203.00
Stream Length	9.57	8.15	5.99	2.98	5.77	3.72
# of Strm.Seg.	10.05	10.7	5.76	4.47	6.05	3.85
Relief Ratio	191.92	86.52	204.97	68.49	273.81	77.42
Drainage Density	1.56	.38	1.26	.31	1.54	.47
Elongation Ratio	.64	.096	.66	.11	.67	.10
Stream Freq.	1.57	.59	1.51	.66	1.84	1.29
Constant of Channel Maint.	.67	.16	.83	.19	.71	.22

A significant amount of information is contained in the other three variables. For instance, relief influences several basin parameters including channel gradient, hillslopes and drainage density (Schumm 1956). Drainage density reflects relief, lithologic characteristics and hydrologic influences. Thus, inferences about rock types, geologic uniformity and infiltration rates can be deduced from this variable for areas of similar climatic influences (Ward 1975, Branson et al. 1981). Stream or channel frequency is dependent on slope and size of drainage area (Horton 1945).

These significantly different variables accounted for approximately 50% of the discrimination power of the final analysis. The final eleven percent can be attributed to the interrelationships of the other five variables which appeared to enhance group separation.

TABLE 16

T-TESTS BETWEEN THREE WATERSHED GROUPS FOR NINE VARIABLES

Variable	Group	Mean	T-Value	
Relief	2	660.78	-1.23	**
	3	716.2		
	2	660.78	-1.88	**
	4	758.07		
	3	716.2	- .98	**
	4	758.07		
Stream Length*	2	1.68	.07	NS
	3	1.67		
	2	1.68	- .1	NS
	4	1.71		
	3	1.67	- .25	NS
	4	1.71		
Elongation Ratio	2	.64	-1.21	**
	3	.67		
	2	.64	-1.47	**
	4	.68		
	3	.67	- .43	NS
	4	.68		
Drainage Density*	2	.51	4.73	**
	3	.21		
	2	.51	2.56	**
	4	.31		
	3	.21	-1.67	**
	4	.31		
Stream Segments*	2	1.97	1.52	**
	3	1.7		
	2	1.97	.77	NS
	4	1.82		
	3	1.7	- .79	NS
	4	1.82		

TABLE 16 (cont.)

Variable	Group	Mean	T-Value	
Sq.Rt.Stream Freq.	2	1.41	3.88	**
	3	1.03		
	2	1.41	2.46	**
	4	1.14		
	3	1.03	-1.56	**
	4	1.14		
Constant of Channel Maintenance	2	.1	-4.85	**
	3	.13		
	2	.1	-2.59	**
	4	.12		
	3	.13	-1.58	**
	4	.12		
Relief Ratio*	2	5.27	.03	NS
	3	5.27		
	2	5.27	1.03	**
	4	5.39		
	3	5.27	-1.61	**
	4	5.39		
Area*	2	1.18	-1.47	**
	3	1.46		
	2	1.18	- .99	**
	4	1.39		
	3	1.46	.49	NS
	4	1.39		

*	Values are in natural logs (ln)
**	Significant (α =.05)
NS	Non-Significant

Comparison of North Fork Parameters with Group Parameters

The North Fork of Elk Creek is located within hydrologic Region Two identified by Potts (1983). A comparison of group morphometric means with values calculated for the drainages of the North Fork are summarized in Table 17. Only two categories show significant differences from the mean, area and elongation ratio. The difference in areas was expected. Watershed selection was subjective only in that the entire drainage needed to fit on a single quadrangle map. Had the selection process been more rigorous, using stream order for instance, as a selection criteria, then the difference would have been more meaningful, as stream order is a function of area (Horton 1945). The elongation ratio is a measure of basin shape which is related to flow concentration. As basin shape approaches that of a circle its calculated value nears one (Schumm 1956). A circular shape is supposedly the most efficient in terms of concentrating precipitation input. The shape of the North Fork approximates an ellipsoid, much greater in length than in width. Thus, the difference in elongation ratios is understandable.

Table 17 illustrates that the North Fork compares rather well morphometrically, with other watersheds in hydrologic Region Two. Is is possible to infer from these hydrologic and geomorphic similarities that catchment output in the form of sediment yields could also be similar? Many morphometric attributes calculated in this study are related to sediment yield (Hadley 1961, as cited by Branson et al. 1981). A dominant factor unmentioned by this study still plays a key role, the

TABLE 17

T-TESTS BETWEEN WATERSHED GROUP 2 AND
WATERSHEDS OF THE NORTH FORK OF ELK CREEK
FOR EIGHT GEOMORPHIC VARIABLES

Variable	Group 2		Drainage A		Drainage B		Drainage C	
	Mean	STD.Dev.	T-Value		T-Value		T-Value	
Area	5.91	4.38	2.56	**	-1.12	NS	.65	NS
Relief*	6.51	.26	- .62	NS	- .32	NS	1.62	NS
Stream Length*	1.95	.79	-1.76	NS	-1.34	NS	.45	NS
No. Stream Seg.*	1.87	.95	-1.55	NS	- .99	NS	.28	NS
Relief Ration*	5.16	.44	1.3	NS	.99	NS	- .13	NS
Elongation Ratio	.63	.09	5.36	**	-3.14	**	2.62	**
Drainage Density*	.42	.24	- .89	NS	- .9	NS	- .57	NS
Sq.Rt.Strm. Freq*	1.22	.28	- .26	NS	- .08	NS	- .19	NS

*	Values in natural Logs (Ln)
**	Significant (α=.05)
NS	Non-Significant

erodability of the substrate. Sediment availability has been the limiting factor in several past studies (Scott 1983, Leaf 1966), the result of bedrock erosive resistance. The amount of sediment generated within a basin is dictated to a large extent by the erodability of the parent material (Anderson 1951). This in turn is related to amount of vegetative cover and the intensity of the climatic regime. Thus, to extrapolate sediment yields from the North Fork to other watersheds in the same hydrologic classification would be an unappropriate simplification of a very complex system.

The results of these analyses did appear to validate the concept of hydrologic regionalization suggested by Potts (1983). It would be interesting to combine average discharge with some of the geomorphic variables tested in this study. Such an incorporation of hydrologic and morphometric variables may strengthen the predictive capabilities of the present regionalization models.

CONCLUSION

Geomorphic parameters of the North Fork compared very well with those of other watersheds in the same hydrologic classification. Although these comparisons showed a strong geomorphic similarity, the temptation to extrapolate sediment yields from one watershed to another based on this relationship should be avoided. The link between hydrologic processes and geomorphic characteristics is still in need of refinement. Suspended sediment yields are influenced by both factors, thus a prediction based on the knowledge of one could only prove to be erroneous. Prediction models such as that suggested by Potts (1983), where both hydrologic and geomorphic influences are combined, have the best chance for success in estimating natural sediment production in ungauged watersheds. Refinement of these techniques will lead to more precise predictions and be an asset to more accurate assessment of management activities.

VALIDITY OF RESULTS

This study was of short duration. Consequently, the findings of this report may not be totally representative of areal processes. The observations made were a brief glimpse into a very complex, highly variable system, the uniqueness of which should not be underestimated. In dealing with hydrologic phenomenon the longer the period of record, the more reliable the information it yields. One of the purposes of this study was to initiate baseline information so that a continuous record might be established.

RECOMMENDATIONS

The sediment sampling and discharge monitoring for the North Fork should be continued. It takes from five to seven years of continuous records to extablish a hydrologic base for small watersheds. As patterns emerge, subsequent correlations and interpretations can be made with greater certainty.

Several improvements and additions can be made to make the study more economical and conclusive. The first suggestion is to improve access to the upper gauging stations. Since a road connects all gauging sites, it makes sense from the aspect of time efficiency to utilize it for sample collection and equipment maintenance. The road is currently impassable at a point about a half mile from the upper station. Transporting batteries and bulky equipment to these sites is time consuming and inefficient. Thus, several yards of washed drain rock should be deposited in the restricting portions of the road. Washed drain rock would reduce the probabilty of generating sediment that could reach the stream and bias baseline data.

Secondly, the sediment sampler at gauging site C should be relocated to a point above the back water created by the weir. This would produce more accurate suspended sediment data. Along the same lines, the sampling schedule should be increased. This would aid in further identification and refinement of suspended sediment-discharge relationships. This alternative is only feasible if access is improved.

The final suggestion is to create a measureble bedload trap at each gauging site to acquire data on this portion of the sediment load to these undisturbed drainages. This knowledge would be valuable in the future as the effects of vegetation manipulation are assessed.

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