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Turbidity - Suspended Sediment Relations In a Subalpine Watershed

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TURBIDITY - SUSPENDED SEDIMENT RELATIONS IN A SUBALPINE WATERSHED

by

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Thomas A. Holstrom

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Turbidity - Suspended Sediment Relations

In a Subalpine Watershed

by

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The effect of particle size distribution of suspended sediment upon a turbidity reading at a known concentration has been relatively quantified for stream bank materials on the Moccasin Basin - North Fork Fish Creek (MB-NFFC) Watershed, located in northwestern Wyoming. As expected, an increase in the median particle size in suspension results in a decrease of turbidity at a given concentration. The relationship derived correlates the particle size distribution of a chemically dispersed stream-bank material sample, with the Coefficient of Fineness for a mechanically dispersed portion of the sample. The relationship appears as:

$$\frac{C_t}{T} = \theta_1 (d_{50})^{\theta_2}$$

where: C_t/T = Suspended sediment concentration (mg/l)/turbidity (NTU) = Coefficient of Fineness

d_{50} = Median particle diameter in centimeters

θ_1, θ_2 = Least Squares regression coefficients

The above relationship was used in conjunction with Yang's transport equation to predict suspended sediment concentration given turbidity, streamflow data (depth, velocity, temperature), and average stream slope.

A method is presented for calibrating Yang's equation, equivalencing the calibrated equation with the relationship derived in this study, and predicting suspended sediment concentration from turbidity, without benefit of gravimetric analysis.

(92 pages)

INTRODUCTION

The problem of sediment erosion and transport in waterways has become an important and expensive pollutional problem to be faced. Excess sediment transport and deposition may reduce the storage capacity of reservoirs, adversely affect aquatic life and habitat, increase production costs for industry and agriculture, which are dependent upon pure water, and increase the cost of treatment for potable water supplies. All of these adverse costs must ultimately be borne by the general public.

Direct measure of suspended sediment in transport is important for providing a data base for research and management purposes. Due to the dynamic nature of streamflow and sediment transport, a large number of suspended sediment samples is required to ascertain sediment production capabilities for just one stream. When considering all the waterways in this country where quantification of sediment production is important, the number of suspended sediment analyses required becomes staggering. Techniques which would yield adequately accurate suspended sediment information in a minimal amount of time will save vast amounts of time, effort, and money.

At present, gravimetric laboratory techniques are the only acceptable ways to measure suspended sediment. (APHA et al, 1975) Use of the turbidity measure to estimate concentration has generally been discouraged. Characteristics of the sediment including particle size distribution, refractive index, specific weight, and shape factor all affect the optical properties of a suspension. The one major redeeming quality of the turbidity measure is the speed and ease with which it can be taken. Only a fraction of the time required for gravimetric analyses is needed to take a turbidity measure. In addition, turbidity mesaure may readily be taken in the field while gravimetric analysis requires substantial laboratory equipment.

In cases where the suspended sediment characteristics remain constant, the turbidity-concentration relationship may be fairly well defined. Kunkle and Comer (1970) found a good correlation between turbidity and suspended sediment concentration on the Sleepers River in northern Vermont (r=.907); however, their average error in determining concentration via turbidity was still 25 to 30 percent. They concluded also that the prediction equation they developed was only accurate for the watershed involved in their study.

In natural systems the characteristics of suspended sediment may change dramatically over time and space as streamflow hydraulics change and available sources of sediment are different. This change may be reflected in differences in the turbidity-concentration relationship. This conclusion is supported by the fact that the slope of the regression equations relating suspended sediment concentration to turbidity is different for each of eight streams sampled on the Moccasin Basin - North Fork Fish Creek watershed in northwestern Wyoming (Holstrom and Hawkins, 1977). Note, for example, the slope of Red and Calf Creek's rating curves in Table 1. As the slope of the rating curve decreases, a higher turbidity results from a given concentration of suspended sediment.

One characteristic of the suspended sediment which has been recognized to dramatically alter the turbidity-concentration relationship has been the particle size distribution of the sediment. The term 'Coefficient of Fineness', defined as the ratio of concentration (mg/l) to turbidity (turbidity units) (Bull and Darby, 1928) has been observed to change depending upon streamflow conditions and available sediment characteristics (Grassy, 1943). This study will attempt to determine the effect that varying particle size distribution of suspended sediment has upon the slope of the turbidity-concentration rating curve (Coefficient of Fineness) for available sediments on the Moccasin Basin - North Fork Fish Creek Watershed.

Table 1. Suspended sediment concentration versus turbidity for the 1976 field data on the Moccasin Basin--North Fork Fish Creek Watershed

		Regression Equation $C_t = a + bT$					
Stream	n	$\overline{T}$	$\overline{C}_t$	a	b	r^2	S_{yx}
Papoose	8	21.6	74.3	-12.5	4.01	.954	18.77
Squaw	8	12.3	36.9	-10.4	3.86	.995	2.68
N. Fork above Calf	7	6.3	16.0	-3.3	3.03	.928	4.87
N. Fork Outlet	7	7.9	19.5	-8.7	3.54	.977	3.16
Hardscrabble	8	11.9	30.3	-0.3	2.55	.980	6.17
Calf	7	7.5	22.1	-3.7	3.44	.676	12.58
Red	8	22.7	37.5	-4.6	1.85	.982	5.63
Beauty Park	7	3.2	6.8	-4.4	3.55	.892	1.61

Notes: From Holstrom and Hawkins, 1976. T in NTU, C_t in mg/l.

Should the effect of particle size distribution of the suspended sediment on the turbidity-concentration relationship be consistent and reliable, then the credibility of the turbidity measure may be much improved. It is conceivable that a turbidity measure could lead to the following estimates in a very economical way:

1) The amount of suspended sediment being transported by a stream, and
2) The particle size distribution of the suspended sediment.

Both estimates may be useful in determining transport capabilities of the stream, and possible sediment sources.

Objectives

This study will attempt to show the following: 1) that a turbidity measure estimate of concentration of suspended sediment is a quantifiable function of the particle size distribution of the sediment, and 2) the function derived for Objective 1 above may be used, in conjunction with streamflow and turbidity data only, to arrive at acceptably accurate estimates of suspended sediment concentration without the need for gravimetric laboratory analysis.

Scope

This study was conceived as the result of a previously performed sediment monitoring study on the Moccasin Basin--North Fork Fish Creek watershed, a subalpine mountain watershed located on the Bridger-Teton National Forest in northwestern Wyoming. Data from that study, conducted in 1976, appear in Appendix A. All analyses were performed for this study on data from the watershed. Streams showed varying configurations due to differences in slope, bed and bank armoring, soil types incised by the streams, and bank and upland vegetative cover characteristics. The major portion of runoff and sediment production occurs due to snowmelt during the spring and early summer months of the year.

LITERATURE REVIEW

Turbidity

Turbidity has been defined as "an expression of the optical property that causes light to be scattered and absorbed rather than transmitted in straight lines through a sample" (APHA, 1975). The methods by which turbidity is measured are implied in the above definition.

Early attempts to measure turbidity were based upon transmittance of light through the sample. The Jackson Candle Turbidimeter and Diaphanometer, used during the early 1900's, operated on extinction of a light source as transmittance of a sample was reduced by increasing the length of travel of light through the sample. Transmittance through a sample was assumed to have a logarithmic decay with concentration and path length known as the Beer-Lambert Law (Ekern, 1976). In equation form it appears as:

$$I = I_o e^{kCL} \qquad (1)$$

where:
- I = transmitted light intensity
- I_o = incident light intensity
- C = particulate concentration
- L = path length of light through the sample
- k = a constant

The constant 'k' was found to vary depending upon the properties of the sediment in suspension.

Turbidimeters operating on extinction principles are impractical at very low turbidities. For instance, the Jackson Candle Turbidimeter has a usable range only above 25 Jackson Turbidity Units (JTU)(Hach, 1972).

In addition, the lack of a good standard calibration suspension and the variation of the 'k' coefficient with differing suspensions made use of extinction turbidimeters tenuous.

In 1926 a good turbidity standard suspension called 'Formazin' was developed (Hach, 1972). The advent of this standard suspension led to the development of photoelectric turbidimeters. Two types of these instruments are common; those that measure light transmittance, called absorptometers, and those that measure the scattering of light at an angle (usually 90°) to the incident beam, called nephelometers.

For several reasons nephelometers have proven superior to absorptometers (Hach, 1972). They are more sensitive at low turbidities; they are less sensitive to dissolved color; and their photoelectric response is directly rather than inversely proportional to an increase in turbidity. In addition, forward scattering of light, especially due to larger size particles, may be quite substantial (Black and Hannah, 1965). This could lead to variable readings of transmittance.

Some physical aspects of light scatter

The physical properties of a suspension of particles is intimately related to its ability to scatter an incident beam at 90 degrees. The particle size distribution is perhaps the single most important physical property of the suspended material altering this scatter. Rayleigh (1871) has shown that for particles much smaller than the wavelength of an incident light beam the radiant intensity of scattered light is proportional to the sixth power of the median particle diameter (see also Stutz, 1930 and Jerlov, 1968). The particle becomes an oscillating dipole as the incident light energy excites it, and emits light radiation in all directions. The relation is:

$$I = \frac{k\, d_{50}^{6}}{\lambda} \qquad d_{50} < < \lambda \tag{2}$$

where: I = radiant intensity perpendicular to the incident beam
d_{50} = median particle diameter
λ = wavelength of incident light
k = a constant

It is noteworthy that pure liquid molecules may act as extremely small particles and scatter light to varying degrees depending on the liquid. This scatter is expressed in absolute terms as the ratio of scattered light at 90° to the quantity of light transmitted through the liquid per centimeter of liquid path length (called the Rayleigh Ratio, R_{90})(Hach, 1972). The value of R_{90} for pure water is approximately 0.865 X 10^{-6} per centimeter. Although this value is extremely small, nephelometric turbidimeters in use today are 'zeroed' on a blank of pure liquid before readings are taken.

Mie (1908) showed that for particles larger than about 0.01 microns in diameter the intensity of scattered light was a function of the median particle diameter, the wavelength of light, and the refractive index of the particles. While his findings substantiate Rayleigh's use of wavelength and median particle diameter, Mie included refractive index of the particles as an important parameter. For a discussion of the Mie Theory for light scatter, the reader is referred to Van De Hulst (1957).

The physical-chemical aspects of some suspensions influence their light-scatter characteristics. Grassy (1943) implies that a turbidity measure of a given concentration showed no relation to either concentration of dissolved solids or specific conductance of the solution. Upon converting Kaolinite from the calcium form to the sodium form, Rebhun and Sperber (1967) found no appreciable change in the size of the mineral clay particle or the optical properties of its suspensions. However, it is still commonly believed that a large dispersing monovalent ion (such as sodium) will result in a higher turbidity reading at a given concentration (Ekern, 1976). Conversely, an increasing electrolyte concentration of polyvalent species should have a flocculating effect on clay particles, thus increasing their effective diameter (Swift, et al, 1972) and decreasing the turbidity imparted by a given concentration. The effective diameter is defined as "the diameter of a sphere having the same density and settling velocity as the particle under study" (Gibbs, et al, 1971). The percent organic matter in a suspension should also affect the turbidity measure as refractive indices and shape factor of the organic material will differ from that of inorganic crystalline mineral sediments.

It is apparent that a turbidity measure may have little direct relation to concentration of suspended matter on a consistent basis due to the many factors involved. As late as 1946, Standard Methods expressed turbidity as 'parts-per-million turbidity--silica scale' and some studies have assumed that turbidity units roughly equalled parts-per-million or milligrams per liter suspended matter (Hornbeck and Reinhart, 1964). Camp (1963) held the view that there is no precise relationship between suspended sediment concentration and turbidity. General concensus seems to imply that under specific circumstances turbidity measure may be quite useful, but general comparative use of turbidity measurement for varied situations is inadviseable.

Particle size distribution

The determination of particle size in stream transport is very important to determine the continued transport or deposition of the particles. It has been shown that particle size distribution does have an effect upon optical properties of the suspension. This effect is utilized in some of the optical techniques for determining particle size distribution of a suspension.

There are four basic methods for determining the particle size distribution of a suspension (Swift, et al, 1972). They are 1) microscopic 2) direct settling methods 3) optical sedimentation and 4) electrical. Only direct settling methods and optical sedimentation methods will be discussed here.

Direct settling methods

Direct settling methods are based on the fact that the density and concentration of a suspension at a certain point in a column of the suspension will decrease over time as the particulate matter settles out. Accurate estimation of the fall diameter of various size particles is essential for proper analyses of particle size distribution by direct settling techniques.

The terminal rate at which a discrete particle will settle depends upon the frictional resistance of the fluid, specific gravity, size, and shape of the particle (Graf, 1971). For viscous resistance at low

Reynolds numbers ($Re < 0.5$) the terminal settling velocity may be closely approximated by Stoke's Law (1851). The mathematical expression describing the terminal velocity in the Stoke's Law regime is:

$$\omega = (g/18)\ ((\rho_s - \rho_1)/\mu)\ d^2 \qquad (3)$$

where:
- ω = terminal settling velocity of the particle
- g = acceleration due to gravity
- μ = dynamic viscosity of the water
- ρ_s = density of the particle
- ρ_1 = density of the water
- d = effective particle diameter

Any consistent set of units may be used with equation (3). For quartz grains of specific gravity 2.65 in quiescent water, the Stoke's Law is applicable to grains less than about 10^{-2} cm in diameter (Fair, Geyer, Okun, 1968). Gibbs, Matthews, and Link (1971) found Stoke's Law to be quite applicable for glass spheres of uniform size, up to about the 5×10^{-3} cm size. Larger particles impart a turbulence about them as they settle (represented by a larger Reynolds number). A transition phase between laminar and turbulent settling occurs for particles between about 10^{-2} cm and 4×10^{-1} cm in diameter (again for quartz grains). Turbulent settling in quiescent water ($Re > 2000$) is applicable for larger particles. Equations for the transition phase and the turbulent phase of settling have been developed experimentally and are available in any standard sedimentation text.

The pipet method (Jennings, Thomas, and Gardner, 1922) and the hydrometer method (Buoyocos, 1928) are two of the common direct settling methods used today. Other direct settling techniques include the visual accumulation tube method, the bottom withdrawal tube method, and some centifuge techniques (for measurement of particles in the submicron range, down to .025 microns) (Vanoni, et al, 1975). The pipet method involves the extraction of small portions of the suspension at a point in the column and the measurement of the change in concentration of these subsamples over time. The hydrometer method utilize the change in density at a point in the column, which is reflected in the height at which a hydrometer will float at rest in the suspension. Both methods have the major disadvantage that suspended solids concentration requirements for the analyses are seldom achieved with naturally occurring suspension of sediments. For instance, 50 grams of material is usually required for the standard hydrometer analysis. Attempts to artificially increase concentration by decantation (Krunbein and Pettijohn, 1938) inevitably result in removal of a portion of the extremely fine sediment. Both methods have proven quite reliable, with accuracy increasing for those suspensions of predominantly finer size particles (Vanoni, et al, 1975).

Optical sedimentation methods

Optical sedimentation methods have proven to be more sensitive than direct settling methods (Swift and Pirie, 1970). This means that adequate results have been obtained at much lower concentrations than those required for direct settling analysis. Optical methods for determining particle size distirbution of suspended sediment closely parallel those used in measuring turbidity. Morrison (1919) was first to use the 'photoextinction' sedimentation technique. Actually, complete extinction of the transmitted light through a settling sample was not desireable. The change in the intensity of the transmitted light over time was a function of the settling characteristics of the sediment. The mathematical basis supporting this relationship drew heavily upon the complex Mie theory previously mentioned (Rose, 1953).

Light scattering mechanisms have proven more sensitive than photoextinction methods (Jordan, et al, 1971)(Swift, et al, 1972), just as with turbidity measure. Stomm and Svedberg (1925) used a series of photographic plates which were exposed over time as sedimentation took place. The change in density of the column of sediment was determined from the photographic negatives. The Interagency Committee on Water Resources (1963) used a recording turbidimeter developed by the General Electric Company as part of a device which determined concentration and particle size distribution from measures of transmitted and scattered light. Manufacture of the turbidimeter was discontinued due to poor reproducibility among samples of differing compositions.

Summary

The turbidity measure is not regarded as a reliable estimate of concentration. Factors affecting the turbidity-concentration relationship include the particle size distribution of sediment, specific gravity, shape factor, refractive index, and wavelength of light incident upon the sediment. If other factors are assumed equal, the particle size distribution of the sediment has a major influence on the turbidity measure at a given suspended solids concentration. This conclusion appears substantiated by the fact that similar optical methods for determining both turbidity and particle size distribution have been employed. Acknowledgement of a turbidity-concentration-particle size distribution interaction is implied in the term 'Coefficient of Fineness' (Bull and Darby, 1928) where:

$$CF = C_t / T \quad (4)$$

and:
CF = Coefficient of Fineness
C_t = Suspended sediment concentration (in mg/l)
T = Turbidity (in appropriate turbidity units)

As turbidity increases for a given concentration, CF decreases, implying the suspension is of finer grained particles (Camp, 1963). This makes sense intuitively. The term 'Coefficient of Fineness' will be used throughout this study.

THE STUDY AREA

Location and Size

The Moccasin Basin--North Fork Fish Creek watershed (hereinafter referred to as the MB-NFFC watershed) is a 43.2 square mile watershed located in the north Gros Ventre mountains on the Bridger-Teton National Forest in Teton County, Wyoming (T.43N., R.111W.). It abuts on the west side of the Continental Divide and lies at an elevation range of 7960-10400 feet. Water quality data for the summers of 1976 and 1977 were obtained from eight sampling stations shown in Figure 1. More physiographic data for the watershed appear in Table 2.

Table 2. Sub-drainages for the Moccasin Basin--North Fork Fish Creek Watershed

Basin	Area (mi^2)	Elevation (ft) Maximum	Elevation (ft) Minimum	Approximate Length of Main Channel (mi)
Red	5.11	9400	8000	3.6
Hardscrabble	2.24	9900	8035	2.9
Beauty Park	3.21	9900	8130	2.9
Calf	3.90	10400	8280	3.4
Moccasin	12.30	10400	8600	7.1
Squaw	8.06	9500	8000	5.3
Papoose	5.09	10000	8000	4.0
Interfluvial Lower Fish	3.25	8600	7960	5.1
TOTAL Watershed	4 3.2	10400	7960	

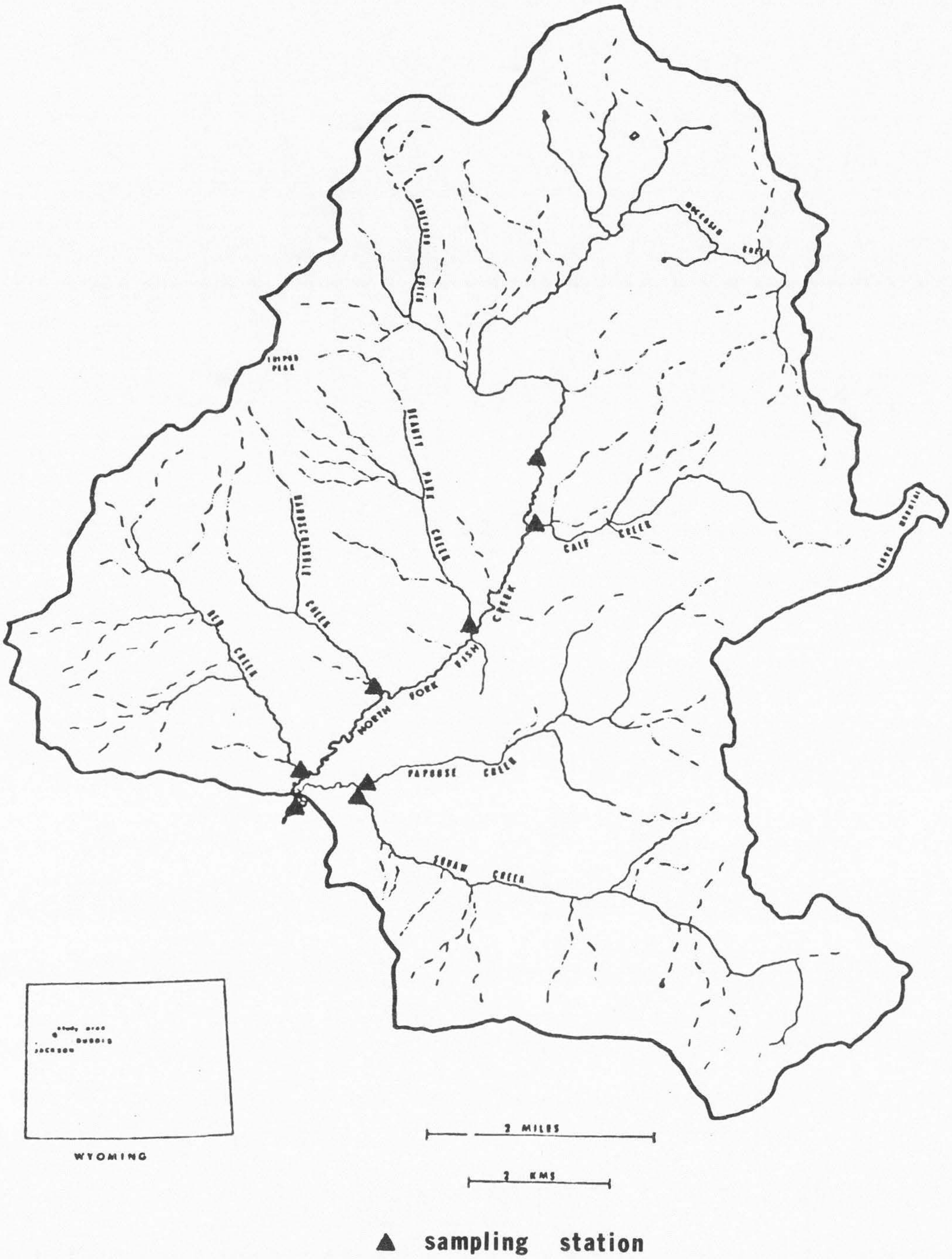

Figure 1. The Moccasin Basin--North Fork Fish Creek Watershed

Geology

The largest portion of the MB-NFFC watershed is underlaind by the Wind River and Indian Meadows Formation. This rock is composed of a lower variegated claystone sequence consisting of soft red and white claystone which is incised and conspicuously outcrops along Red, Hardscrabble, and the lower portions of the Papoose and Squaw Creeks (Love, 1956). Bed and bank armoring is generally poor and channel sources of fine-grained suspended sediment are nearly continuous along these streams.

At higher elevations toward the Continental Divide, Papoose and Squaw Creeks have cut into an underlying andesite tuff. This is demonstrated by the improved bed armoring in the form of cobbles. In some lower reaches of Squaw Creek incisement has exposed what appear to be large basalt rocks along the stream bed.

Northward, Calf Creek has cut through alluvium at higher elevations, leaving a cobbly, rocky bed over the major portion of its length. Basalt rocks are nearly continuously exposed in its lower reaches. Beauty Park Creek exhibits the same progression of bottom materials from the higher to lower elevations of its length.

The North Fork of Fish Creek exhibits an increase in stable bottom materials as one goes from its lower to upper reaches. Fine-grained, moveable sediment is exposed in the lower reaches where Red, Papoose, Squaw, and Hardscrabble Creeks join the North Fork. Immediately north of the confluence of Beauty Park Creek, what appear to be basalt cobbles and stones are exposed in the bed of Fish Creek. These stable bottom materials increase in size as one travels up to about a mile above

Hereford Creek. Farther north, grades become less steep and the upper reaches of the North Fork and Moccasin Creek again cut through alluvium of the Wind River and Indian Meadow Formation (Figure 2 and Table 3).

Water movement through the fine-grained alluvium is assumed to be relatively slow. During the spring melt however, enough water is taken in to lubricate and trigger bank slides and slumps, most readily seen along Red, Hardscrabble, Papoose, Squaw and the North Fork of Fish Creek.

Climate

The climate of the MB-NFFC watershed may be considered as sub-alpine. Although no temperature data have been collected on the watershed itself, it may be assumed that they approach those measured at Moran Junction (25 miles west), which range from 86° F (30° C) maximum to -31.6° F (-35.3° C) minimum. Snow is the predominant form of precipitation with the snowpack accumulating over 6-7 months of the year and yielding its water content as snowmelt runoff during the spring and early summer. Precipitation amounts across the watershed are highly variable, ranging from 31 inches (78.8 cm) in the lower reaches of the basin to as high as 50 inches (127 cm) along the Continental Divide. Rain events during the summer months are usually of low intensity and relatively short duration, although infrequent severe convective storm cells may move across the basin.

Because the entire watershed has a predominant south-southwest aspect, insolation can be quite high, especially on the gentler slopes found in the lower reaches of the watershed and in localized areas of Mocassin Basin.

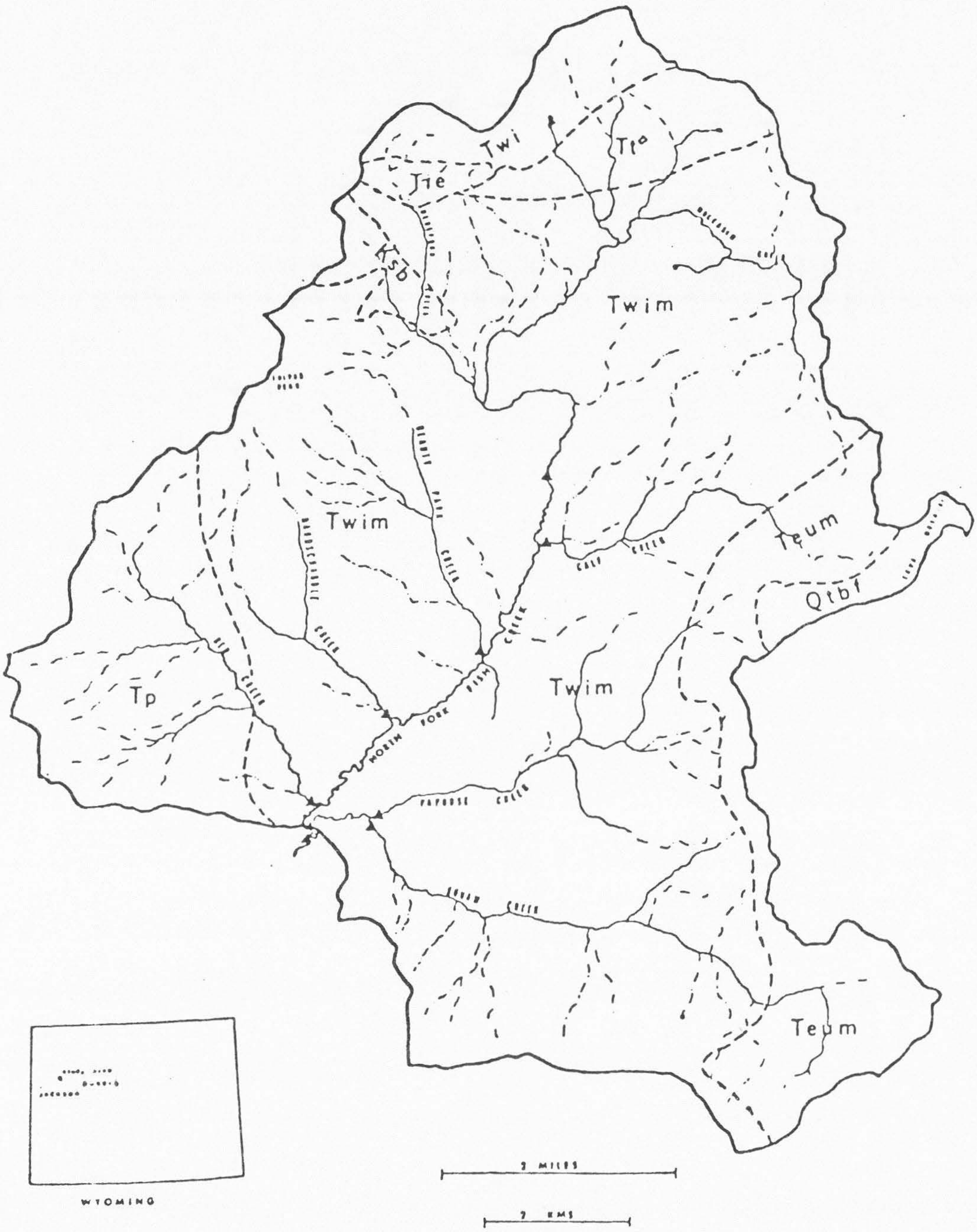

Figure 2. Geology of the Moccasin Basin-- North Fork Fish Creek Watershed. See Table 3 for symbols.

Table 3. Key to the geologic formations in Figure 2.

Symbol	Formation and Description
Twi	Wiggins formation--Reddish-brown to gray andesitic conglomerate interbedded with white tuff and claystone.
Tt	Teepee Trail formation--Green and gray tuffaceous claystone, sandstone, and conglomerate.
Teum	Upper and Middle Eocene rocks, undivided--Green, gray, and white tuffaceous claystone, sandstone, and conglomerate; underlain by tuffaceous variegated claystone, sandstone, and lenticular quartzite pebble conglomerate.
Twim	Wind River and Indian Meadows formation--Variegated claystone, sandstone, and lenticular locally-derived conglomerate; persistent coal and gray shale in middle of sequence in eastern part of area.
Tp	Paleocene rocks, undivided--Greenish-gray and brown sandstone, claystone and coal in upper part; quartzite cobble conglomerate (Pinyon conglomerate) in lower part; coal and gray shale at base.
Ksb	Lenticular sandstone, shale, and coal sequence and Bacon Ridge sandstone undivided.
	IGNEOUS AND METAMORPHIC ROCKS
Qtbf	Late basalt flows--Red and black vesicular basalt. Includes some dikes and instrusive masses.
Tie	Intrusive and extrusive rocks of uncertain age and composition.

Source: Love (1956).

Soils

In the lower reaches of the watershed, Red, Hardscrabble, Papoose, Squaw, and the North Fork of Fish Creek are incised in soils ranging from gravelly clay loams to clay loams. These soils are from 30-60 inches in depth and are characterized by a high clay content. Slope failures along lower stretches of these streams are frequent and large during the spring snowmelt season when the clay acts as a lubricant on unstable slopes. Infiltration rates are moderately rapid to slow and sheet erosional hazards may be moderately low to high.

Beauty Park Creek and Calf Creek cut soils ranging in texture from loamy sands to loams. Clay content is somewhat lower and slope failures are rare, smaller in size, and confined strictly to the stream channel banks. Infiltration rates are moderately slow to moderate on these two basins and sheet erosional hazards are moderately low. Soil depths range from 20-60 inches.

In the higher reaches of the watershed, Moccasin Creek cuts through soils that are again characterized by a substantial clay content. Gently sloping meadows adjacent to the stream channel preclude any slope failure. Bank cutting, however, is extreme in places. Soil depths on the Moccasin Basin range from 20-60 inches and surface sheet erosional hazards are moderately low to moderately high in the northernmost portion of the basin.

Vegetation

On the MB-NFFC watershed two major vegetal communities predominate. In the lower, more arid regions of the watershed (generally below 8400 feet) a sagebrush/grass community exists. Lower portions of Papoose, Squaw, Red, and Hardscrabble Creeks and the interfluvial North Fork Fish Creek area, all drain this area of generally high range productivity. Soil moisture content is usually low except along the stream channels where a willow-sedge community is established. This is most apparent along the main stem of the North Fork Fish Creek.

At approximately 8400 feet in elevation the sagebrush/grass community gives way to a zone of transition. A combination of pines, firs, aspen, sage and grasses predominate on soils of slightly higher soil moisture content. Lodgepole pine, Engelmann spruce, and subalpine fir are all found in this transition zone along with mountain big sagebrush, yarrow, phlox, and several grasses.

At higher elevations of the watershed a subalpine fir/Engelmann spruce community predominates. Douglas fir, lodgepole pine, and subalpine fir predominate in this community. Soil moisture content is usually high and understory growth, along with litter deposition tends to anchor and protect the underlying soils.

METHODOLOGY

In order to relate the effect of particle size distribution to a turbidity-measure estimate of suspended sediment concentration, three basic analyses must be performed. They are:

1) Particle size distribution analysis,

2) Gravimetric suspended sediment concentration analysis, and

3) Turbidimetric measure of the suspended sediment suspension.

All laboratory analyses were performed on bank samples of soil which would be considered available to the streams for transport. Three analyses were performed on each sample. Particle size distribution of each sample was determined using the Hydrometer technique. Suspensions of each sample were created in the laboratory and concentration and turbidity measurements were made for seven dilutions of each sample suspension. Concentrations of suspended sediment (non-filterable residue) and volatile solids were performed gravimetrically. Turbidity measure was made with the Hach 2100A nephelometer.

Field Work

During the 1977 summer field season, five soil samples of from 100 to 200 grams each were collected at a distance between ¼ and ½ mile upstream from each of the eight sampling stations on the MB-NFFC watershed shown in Figure 2. These samples were scraped from exposed bank materials at an elevation above the stream bed no higher than the typical high water line for a normal year of streamflow. In all cases the first sample was taken nearest to the sampling station, and each succeeding sample was taken in an upstream progression. Uniform compositing of samples was allowed in attempting to get a representative group of samples for the entire ¼ to ½ mile reach above each station. Samples were stored in plastic bags for transport. They were air dried upon return to the lab, and oven dried (103-105° C) prior to analysis.

Laboratory analysis of particle size distribution

After oven drying, the samples were sieved through a 2.0 millimeter (#10) mesh sieve. Some samples with high clay content showed an extreme amount of cementation upon drying. These samples were broken down with mortar and pestle prior to sieving. Use of the mortar and pestle was held to a minimum, i.e., just enough to obtain an adequate amount to pass through the 2.0 mm sieve for analysis (about 60 grams).

Fifty grams of each sample were extracted for particle size distribution analysis by the hydrometer method. Details of the hydrometer method used were outlined by the American Association of State Highway and Transportion Officials (1974). The fifty grams were covered by 125 milliliters of a sodium tetraphosphate ($Na_6P_4O_{13}$) dispersing solution and allowed to stand overnight. Each sample was then dispersed in an electric drink mixer for one minute and poured into a settling cylinder. The cylinder was filled with distilled water up to one liter. The entire suspension was shaken for one minute and set down to settle. Temperature and hydrometer readings were taken at 1, 2, 5, 15, 30, 60, 240 and 1440 minutes. The color of each suspension was determined using the Munsell Color Chart.

Proper calibrations for water temperature, type of dispersing agent, and hydrometer miniscus height were accounted for in computation of the particle sizes and the 'percent passing' a particular size (as if it were sieved).

Laboratory analysis of suspended sediment and turbidity

Four grams of each soil sample were weighed and placed in the mixing cup. The sub-sample was not covered with the dispersing solution. It was felt that chemically-dispersed suspended sediment samples would not reflect the real processes of mechanical suspension and dispersion that occur in a stream. Each suspension was mixed in the drink mixer for one minute and transferred to a one liter volumetric flask. The suspension was brought up to one liter with distilled water and transferred to a two liter beaker. A 3 x ½ inch stirring bar was placed in the beaker and the beaker was placed upon a magnetic stirring apparatus.

Dilutions were made as the suspension was being stirred rapidly enough to keep all particles suspended. A 10 ml graduated pipette (with a slightly enlarged orifice to handle the coarser particles) was used to remove the necessary portions of suspension for the dilutions shown in Table 4.

All dilutions were brought up to 200 ml in volumetric flasks, and transferred to 250 ml PVC sample bottles. Analyses for suspended (non-filterable) residue and percent volatile residue were performed on each dilution gravimetrically at 103-105° C and 550± 50° C respectively, as outlined in Standard Methods (1975). Turbidity readings were taken using the Hach 2100A nephelometer. Three replicates of the most dilute sam-

Table 4. Suspension dilutions for the suspended sediment--turbidity analyses.

Dilution	ml Suspension	ml Dilution Water	Theoretical Concentration (mg/l)
0	200	0	4000
1:1	100	100	2000
1:3	50	150	1000
1:9	20	180	400
1:19	10	190	200
1:39	5	195	100
1:99	2	198	40

ples were completely mixed and readings recorded at five seconds after placement of the cuvette into the nephelometer. Those samples with turbidity greater than 40-50 nephelometric turbidity units (NTU's) were not measured directly. Instead, their turbidity measure was taken to be equal to the previous directly read turbidity measure times the appropriate dilution factor (Standard Methods, 1975).

Numerical analysis of particle size distribution

The percent passing a given particle diameter (sieve size) for each hydrometer reading over time was computed and plotted on semi-log paper, as shown in Figure 3 for Papoose Creek. Computational procedures were performed as outlined in AASHTO (1974). An eyeball fit of the data points for each soil sample made it possible to read directly the approxi-

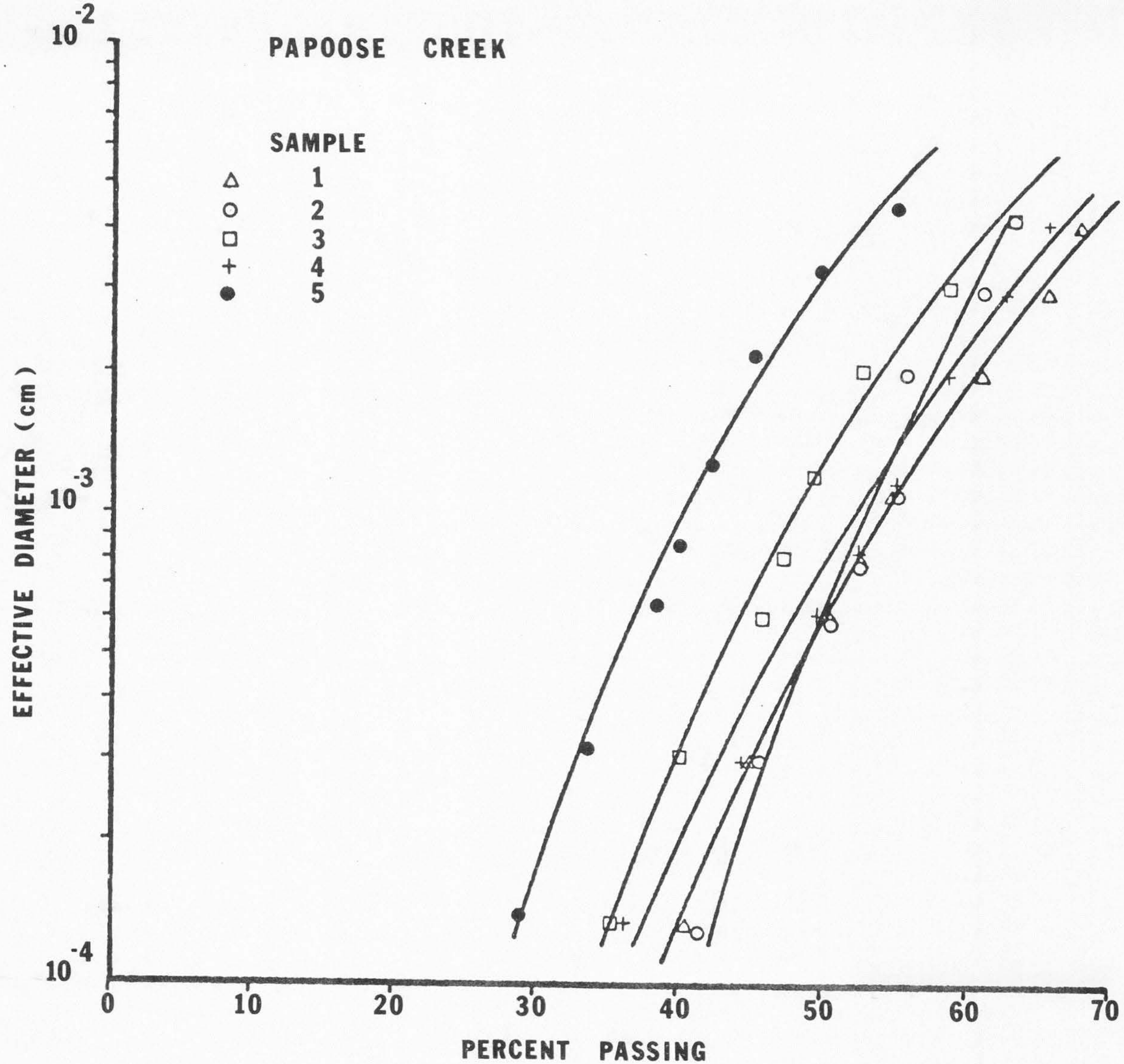

Figure 3. Particle size distribution plot resulting from the Hydrometer analysis of stream bank material.

mate percent sand, silt, and clay and the median particle diameter (d_{50}, effective diameter of the particle of which 50 percent of the sample is smaller). For this study the United States Department of Agriculture size classifications were used (Lyon and Buckman, 1949) and appear in Table 5.

Table 5. Size classification of soil particles by the United States Department of Agriculture

Separate		Diameter limits (cm)
Sand	Coarse Sand	0.1 - 0.05
	Medium Sand	0.05 - 0.025
	Fine Sand	0.025 - 0.01
	Very Fine Sand	0.01 - 0.005
Silt		0.005 - 0.0002
Clay		< 0.0002

Numerical analysis of suspended sediment and turbidity

Suspended sediment concentrations (mg/l) were plotted against the turbidity reading (NTU) for the seven suspension dilutions of each sample. A linear least-squares regression was fit to the seven data points of each sample. It took the form:

$$C_t = bT \tag{5}$$

where: C_t = suspended sediment concentration (mg/l)
T = turbidity (NTU)
b = regression coefficient = Coefficient of Fineness

Note that the regression line is forced through the origin and that the 'b' coefficient is equal to the previously mentioned 'Coefficient of Fineness' (CF). Figure 4 shows the suspended sediment - turbidity plots for the five samples taken on Red Creek.

Combined Analyses

The coefficient of fineness for each sample was plotted against percent sand, percent clay, and d_{50} independently to determine what effect particle size distribution would have upon the turbidity -- suspended sediment relationship. A multiple linear regression was performed with percent sand and percent silt as the independent variables and CF again the dependent variable. A multiple linear regression, regressing percent volatile matter and median particle size, was also performed.

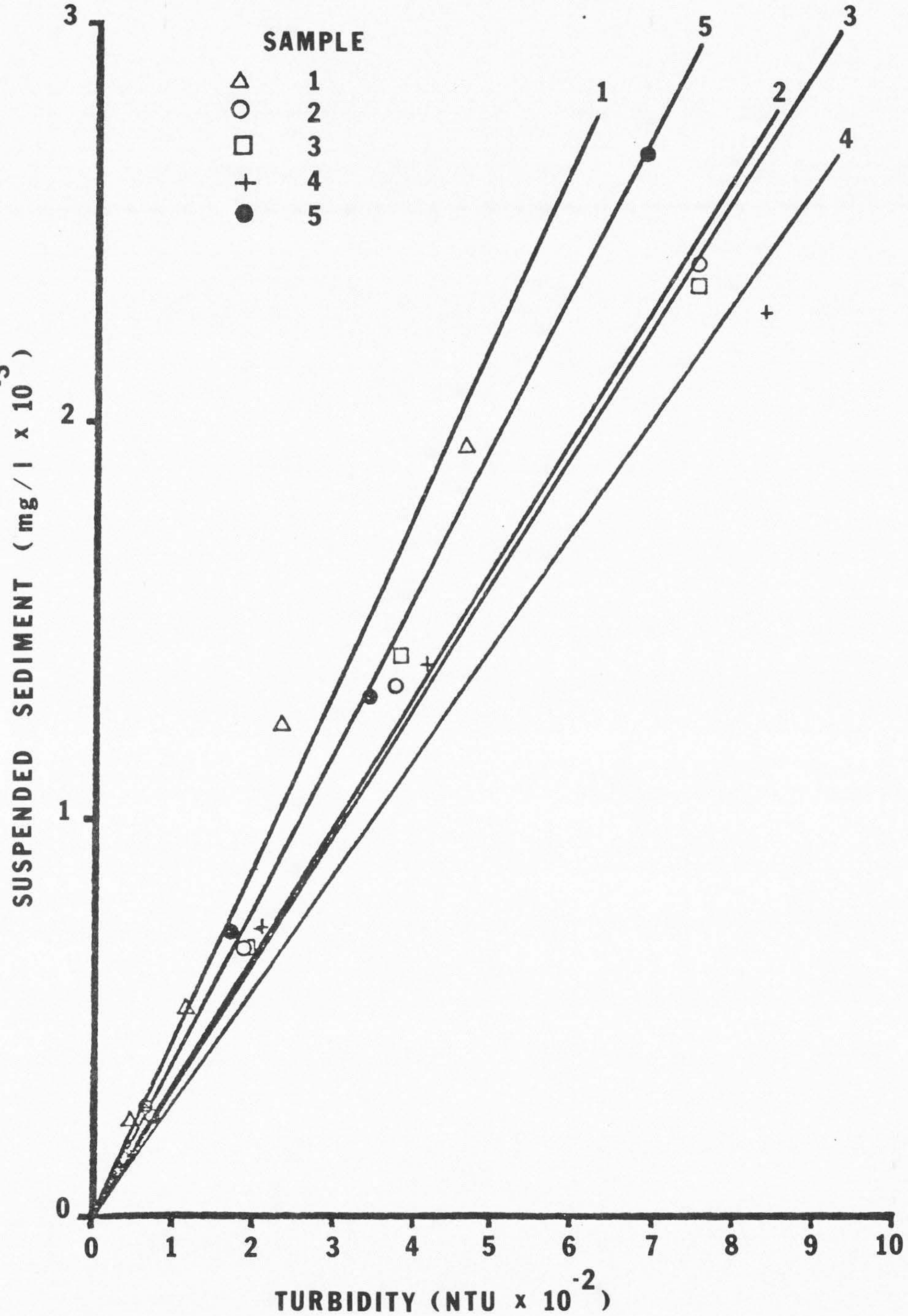

Figure 4. Suspended sediment versus turbidity for the five bank material samples taken above the Red Creek station.

RESULTS AND DISCUSSION

Particle Size Distribution Results

Table 6 shows the average percent sand, silt, clay, and average median particle diameter of the five bank material samples taken above each of the eight stream stations. All particle size distribution and color data appear in Appendix B. An inadequate amount of sample 3 was obtained on Red Creek to perform the particle size distribution analysis and will therefore not be included in any further analyses. Soils above the three upper stations located on Beauty Park, Calf, and the North Fork Fish Creek above Calf, exhibit a lower mean percent clay and a larger median particle diameter than samples taken above the five lower stations on the watershed. Median particle sizes for individual samples ranged from a low of 0.00042 cm diameter on Hardscrabble Creek (sample 3) to a high of 0.013 cm diameter on Calf Creek (sample 3). These results appear generally consistent with the geologic and soil characteristics of the basins in which the streams are incised.

Suspended Sediment - Turbidity Results

In all cases, turbidity correlated very well with suspended sediment concentration. The minimum correlation coefficient (r) relating the two by the '0 intercept' linear regression equation was 0.976. The slope of the regression equation (the Coefficient of Fineness) was different for each sample, as expected, and ranged from 2.632 mg/l per NTU on Papoose Creek (sample 1) to 8.204 mg/l per NTU on the North Fork Fish Creek above Calf (sample 5). Table 7 shows the mean Coefficient of Fineness for the five bank material samples above each station. A complete listing of the CF data appears in Appendix B.

Problems with settling of the coarsest materials in suspension were encountered during transfer of the suspensions to the filtering apparatus (for gravimetric analyses) and to the nephelometer cuvette (for turbidity analysis). It was not determined what sizes of this coarse material were effectively removed from the analysis due to this rapid settling out. This 'truncation' of coarse material should be nearly the same by size for each sample.

Percent volatile solids, which gives an indication of the amount of organic matter in the suspended sediment, ranged from a low of 5.0 percent on the Fish Creek Outlet (sample 2) to a high of 13.3 percent for Squaw Creek (sample 1). The overall mean percent volatile solids for the 40 samples analyzed was 8.32 percent with a coefficient of variation of .255. Volatile solids data appears in Appendix B.

Table 6. Mean particle size distributions for the streambank materials above each of the eight stream stations.

Stream	Mean % Sand	Mean % Silt	Mean % Clay	d_{50} (cm)	Classification
Papoose	35.3	25.5	39.2	.00122	Silt
Squaw	46.6	23.4	30.0	.00429	Silt
N. Fork above Calf	49.9	20.9	29.2	.00522	Very Fine Sand
N. Fork Outlet	40.9	27.7	31.4	.00278	Silt
Hardscrabble	34.9	26.0	39.1	.00071	Silt
Calf	57.3	16.4	26.3	.00864	Very Fine Sand
Red	40.1	27.5	32.4	.00250	Silt
Beauty Park	52.9	20.7	26.4	.00528	Very Fine Sand

Table 7. Coefficient of Fineness values for bank-sample suspensions created from bank material samples taken from above the eight stream stations.

Stream	Coefficient of Fineness Mean (mg/l/NTU)	Standard Deviation (mg/l/NTU)	Coef. Var.
Papoose Creek	3.418	0.617	.181
Squaw Creek	4.387	0.853	.194
N. Fork above Calf	5.725	1.390	.243
N. Fork Outlet	4.798	1.041	.217
Hardscrabble Creek	3.482	0.277	.080
Calf Creek	5.948	1.189	.200
Red Creek	3.529	0.614	.174
Beauty Park Creek	6.605	0.688	.104

Combined Analyses Results

The Coefficient of Fineness is plotted as a function of percent sand and a function of percent clay in Figure 5. A geometric least squares fit was used to describe the function. Its form is:

$$C_t/T = \theta_0 (X)^{\theta_1} \qquad (6)$$

where: C_t/T = Concentration/Turbidity = Coefficient of Fineness
X = Percent sand or clay
θ_1, θ_0 = Lease squares regression coefficients.

As one would expect, the functions are nearly inverse of each other. Coefficients of correlation (r) for the percent sand and percent clay

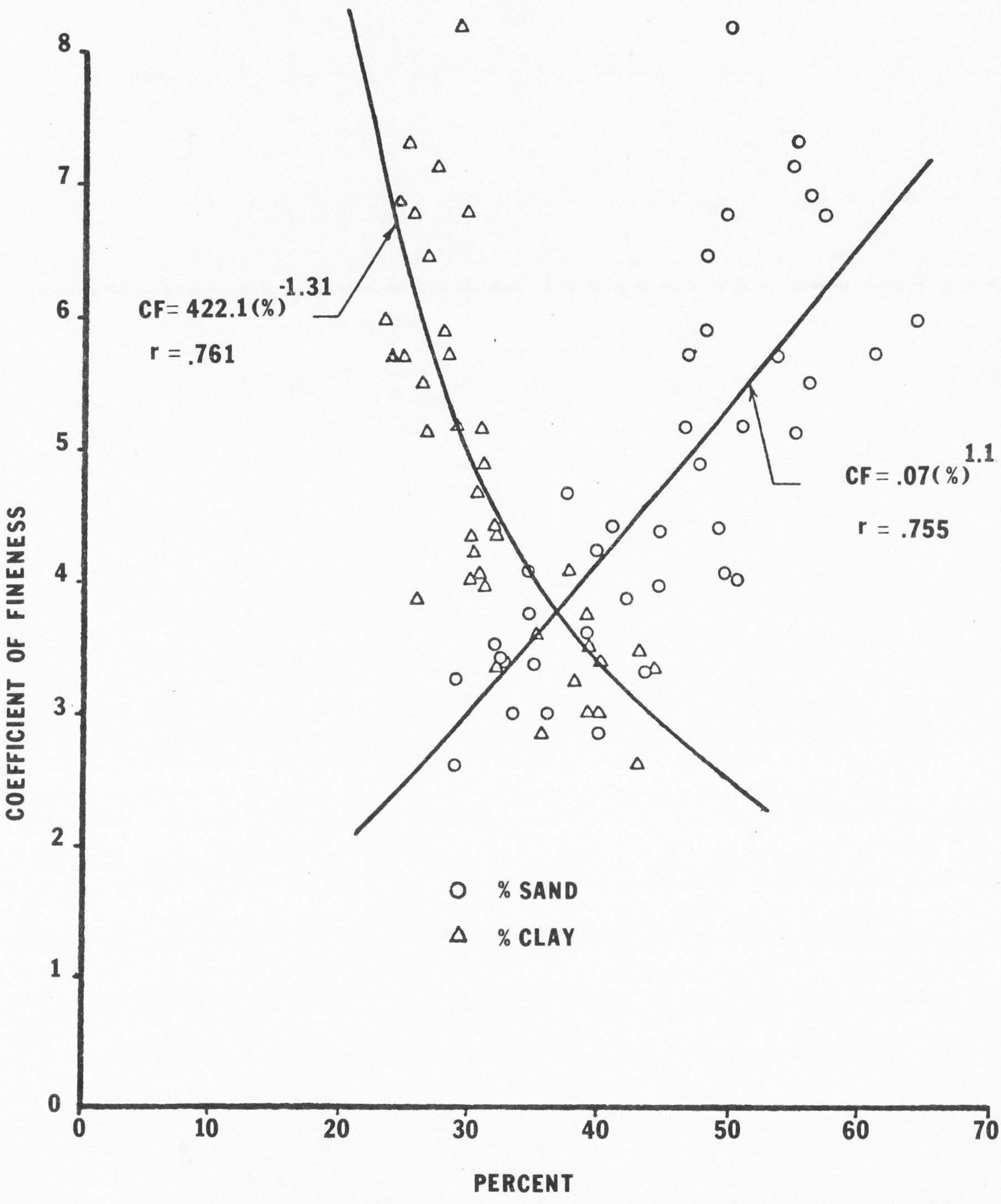

Figure 5. Coefficient of Fineness versus percent sand and percent clay in bank materials on the MB-NFFC watershed.

plots are 0.755 and 0.761 respectively. Multiple linear regression (r) of percent sand and percent silt (percent clay is implied) against CF yielded a slightly improved correlation coefficient of 0.798.

It was felt that representation of CF in terms of the median particle diameter may be most useful. The geometric equation used in equation (6) above was employed. The plot of Coefficient of Fineness versus median particle diameter appears in Figure 6. The correlation coefficient is 0.748.

Clearly, as the median particle diameter in suspension increases in size, so also does the Coefficient of Fineness. This means that a given concentration of coarse particles will have a substantially lower turbidity than the same mass of fine grained particles according to the relation:

$$C_t/(\theta_0\ (d_{50})^{\theta_1}) = T \qquad (7)$$

This equation is merely equation (6) solved for turbidity. For this study θ_0 was found to equal 18.79 and θ_1 was 0.235 when median particle diameter is in centimeters, concentration as mg/l, and turbidity as nephelometric turbidity units (NTU's). It should be remembered that the median particle diameter for each sample was determined for a chemically dispersed suspension while the Coefficient of Fineness was determined for suspensions that were mechanically mixed only. For this reason the derived relationship is descriptive in a relative rather than an absolute sense.

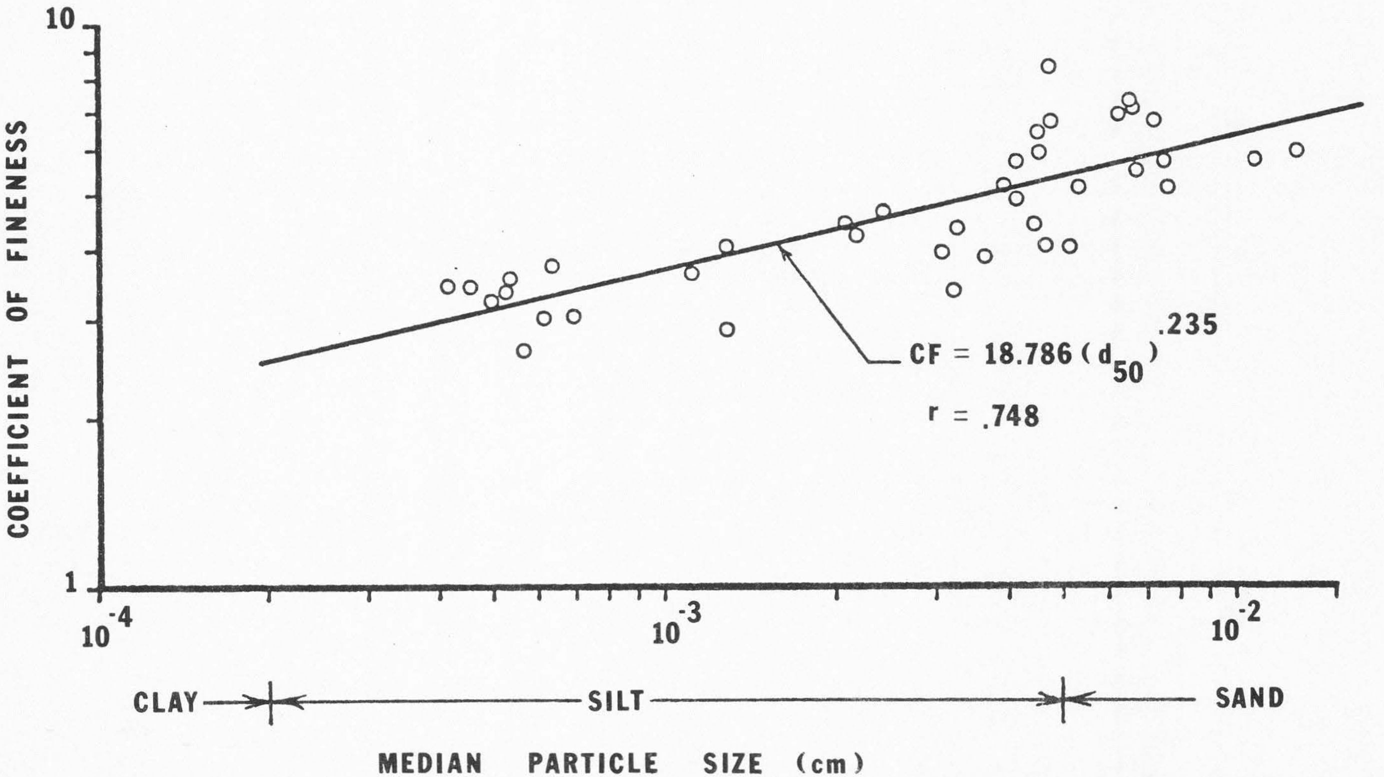

Figure 6. Coefficient of Fineness (CF) versus median particle diameter (d_{50}) of stream bank materials on the MB-NFFC watershed.

APPLICATION OF RESULTS

A logical extension of this work would be to use the relationship between particle size and Coefficient of Fineness to predict concentration, given flow characteristics and turbidity data only. Most suspended sediment transport equations which have been developed include median particle diameter directly, or in the form of terminal settling velocity, along with hydraulic components which affect the size of particles which will remain in suspension. It is hoped that the equation derived in this study may bridge the gap between the physical process description of transport found in most transport equations, and an actual measure (turbidity) indicative of what is being carried in suspension--the common term in both equations being median particle diameter.

Yang's transport equation

Yang (1973) developed a semiempirical transport equation based upon dimensional analysis and multiple regression analysis of a large number of field data. He related 'dimensionless effective unit stream power' to sediment concentration of various size particles. In its basic equation form the relationship appears as:

$$\log_{10} C_t = I + J \log_{10} \left[\frac{VS}{\omega} - \frac{V_{cr}S}{\omega} \right] \quad (8)$$

where:
- C_t = suspended sediment concentration
- V = mean flow velocity
- V_{cr} = critical velocity at incipient motion of a particle of diameter d
- S = energy slope
- ω = terminal settling velocity of the particle
- I,J = regression coefficients

Equation 8 is valid only when the expression inside the brackets is > 0; the V/ω cannot be factored out. Yang (1973) used equation (8) above to develop a generalized equation with I and J related to fluid and sediment properties such that the resulting equation would have some theoretical support and be dimensionally homogeneous. The final forms of I and J selected by Yang are:

$$I = a_0 + a_1 \log\left(\frac{\omega d}{\nu}\right) + a_2 \log\left(\frac{U_*}{\omega}\right)$$
$$J = b_0 + b_1 \log\left(\frac{\omega d}{\nu}\right) + b_2 \log\left(\frac{U_*}{\omega}\right) \quad (9)$$

where: d = particle size
ν = kinematic viscosity of the water
U_* = $\sqrt{gDS}$ = shear velocity
g = acceleration due to gravity
D = mean depth of flow
$a_0, a_1, a_2, b_0, b_1, b_2$ = multiple regression coefficients

Yang's equation was chosen for use for the following reasons:

1) It has been recently developed and shows promise as a predictive equation.

2) It is relatively easy to apply and requires only minimal basic data inputs, all of which are available for this study.

3) The coefficients may be readily obtained by multiple linear regression of actual field data.

Some deficiencies in Yang's equation as he derived it are worth noting. The equation as derived does not identify or separate the physical processes of bedload transport and suspended load transport (Mavis, 1976). Its applicability has been demonstrated only for particles larger than 0.0125 cm in diameter (Jordan, 1977). Yang's calibration of the equation excluded washload sediment particles that are much smaller than sand sizes. Questions have also been posed concerning the verification of the equation on actual data (Nordin, 1977)(Hubbell, 1977).

The use of Yang's equation for this study required four modifying assumptions. First, the median particle diameter (d_{50}) used in the equation for this study represents the d_{50} of the suspended material rather than of the bed material as used by Yang (1976). It follows, therefore, that the critical velocity at incipient motion of the particle, (V_{cr}) for this study is more representative of the velocity required for continuous suspension of the particle and will be a constant upon calibration of the equation. Third, the concentrations used in the calibration of the equation to the field data in this study do include washload particle sizes. And finally, the energy slope term (S) has been replaced with an average slope term computed from topographic data on the MB-NFFC watershed.

Calibration

Concentration, turbidity and hydraulic flow data were compiled for the 1976 summer field season for the eight streams on the MB-NFFC watershed and appear in Appendix A. Depth and velocity of flow were taken as the mean transect values determined during gaging of each stream discharge by the 'velocity-area' method.

For each data point concentration and turbidity measures were put into equation (7) and the equation solved for median particle diameter of the suspended sediment. Use of this computed median particle diameter in calibration of Yang's equation implies the certain following assumptions:

1) The major source of suspended sediment transported by the streams is from exposed cut banks and slides along the stream channels (Holstrom and Hawkins, 1977).

2) The optical relationship between particle size distribution and Coefficient of Fineness derived in this study is assumed to hold for the suspended sediment transported by the streams, as it does for the stream bank materials from which the sediment is assumed to be derived.

3) The sediment transported by all streams on the MB-NFFC watershed is assumed to have the same characteristics, exclusive of particle size distribution, which affect its optical properties in suspension, i.e. the same specific gravity, refractive index, shape factor and organic matter content.

Suspended sediment concentration and turbidity values for the computed average yearly streamflow for each stream were obtained from flow duration, sediment, and turbidity rating curves which were created from the 1976 data (Holstrom and Hawkins, 1977). Median particle sizes in suspension were then computed, again using equation (7) and compared with the measured average particle size distribution of the bank material for each stream. No apparent correlation was found. Measured bank material particle sizes ranged from 1 to 52 times greater than the computed suspended sediment particle sizes at the average year's streamflow for Papoose and Red creeks respectively.

Channel configuration and hydraulic flow characteristics (including slope, turbulence, depth, velocity and water temperature), in addition to differences in available distribution of particle sizes in the bank materials, may all affect which size particles may be transported. To incorporate many of the variables involved which affect the size of particles transported, the more complex form of Yang's equation was chosen for calibration purposes and appears as:

$$\log_{10} C_t = a_0 + a_1 \log \left(\frac{\omega d_{50}}{\nu}\right) + a_2 \log \left(\frac{U_*}{\omega}\right) + \left[b_0 + b_1 \log \left(\frac{\omega d_{50}}{\nu}\right) + b_2 \log \left(\frac{U_*}{\omega}\right)\right] \log \left[\frac{Vs}{\omega} - \frac{VcrS}{\omega}\right] \tag{10}$$

Twenty-seven of the sixty available data points from the 1976 summer field season were discarded for the calibration because their computed median particle diameter in transport was less than .00005 cm. This was considered the lower limit of particle size at which the Stoke's settling equation was still applicable (Kaplan, 1968). Smaller particles may remain suspended indefinitely due to electrostatic VanderWaal's forces and Brownian movement, and thus are not affected by changes in hydraulic transport capability of a stream.

A multiple linear regression procedure was performed on this data to obtain the 'best fit' coefficients to go into Yang's equation. The regression model is of the form:

$$Y = a_0 + a_1X_1 + a_2X_2 + b_0X_3 + b_1X_4 + b_2X_5 \qquad (11)$$

where:

$$Y = \log_{10} C_t$$

$$X_1 = \log\left(\frac{\omega\, d_{50}}{\nu}\right)$$

$$X_2 = \log\left(\frac{U_*}{\omega}\right)$$

$$X_3 = \log\left[\frac{Vs}{\omega} - \frac{VcrS}{\omega}\right]$$

$$X_4 = \log\left(\frac{\omega\, d_{50}}{\nu}\right) \log\left[\frac{Vs}{\omega} - \frac{VcrS}{\omega}\right]$$

$$X_5 = \log\left(\frac{U_*}{\omega}\right) \log\left[\frac{Vs}{\omega} - \frac{VcrS}{\omega}\right]$$

V_{cr} was determined by 'trial and error' to obtain the best fit of Yang's equation to the actual suspended sediment data, and was assumed constant for the data once the best fit was achieved. The coefficient of correlation object function was maximized in arriving at the best fit.

The computer program used for the calibration of Yang's equation appears in Appendix C and incorporates a modified version of WANG Laboratory's multiple linear regression program.

The eight streams on the MB-NFFC watershed were divided into two groups depending upon channel characteristics such as bed and bank armoring and vegetative cover, particle size distribution of bank materials available for transport, slope and hydraulic regime. Beauty Park Creek, Calf Creek, and the North Fork Fish above Calf Creek exhibit more stable bed and bank materials, superior vegetative anchorage of soils, predominantly larger particle sizes available for transport, steeper slopes, and more turbulent flow characteristics than the five lower streams on the watershed. The calibration of Yang's equation for the 1976 data (by altering V_{cr}) was performed for each group of streams. All calibration coefficients for the three calibrations appear in Table 8, along with the optimal V_{cr} to achieve the best fit of the equation to the actual data. Note that the V_{cr} value is higher for the upper station streams carrying the coarser grained material, as it should be. The calibration coefficient of multiple correlation significantly improved upon separating the eight streams into two groups. This improvement may be a statistical phenomenon related to the fact that similarities of streams within the groupings is greater than between the groupings.

Also shown in Table 8 are the multiple linear regression coefficients as determined by Yang for his 'dimensionless unit stream power equation' (equation 10). As can be seen, Yang's coefficients are markedly different from the coefficients determined in this study. Statistical reasons for this have not been investigated and are beyond the scope of this study.

Table 8. Calibration coefficients of Yang's equation fit to the 1976 MB-NFFC field data.

Stream Group	n	a_0	a_1	a_2	b_0	b_1	b_2	V_{cr} (cm/sec)	r	S_{yx}
All streams	33	5.751	-.7625	-1.86	-.333	.147	.261	9.13	.761	.326
Lower streams Squaw, Papoose, Red, Hardscrabble N. Fork Outlet	19	11.411	-3.601	-6.227	-2.803	1.493	2.285	9.03	.929	.207
Upper streams Beauty Park, Calf, N. Fork Above Calf Creek	14	12.949	-4.469	-7.832	.0306	.486	.706	26.40	.930	.158
Yang's Coefficients		5.435	-.286	-.457	1.799	-.409	-.314			

Equivalencing of Equations

Two equations are now available for describing suspended sediment concentration in terms of flow characteristics and turbidity, with median particle diameter common to both. The first equation derived from this study is of the form:

$$C_t/T = \theta_0 (d_{50})^{\theta_1} \qquad (12)$$

which may be logarithmically transformed to:

$$\log C_t = \log \theta_0 + \theta_1 \log d_{50} + \log T \qquad (13)$$

The second equation is Yang's transport equation (equation 10) of the form:

$$\log C_t = a_1 + a_2 \log (kd_{50}^{\ 3}/\nu) + a_3 \log (U_*/kd_{50}^{\ 2})$$

$$+ [b_1 + b_2 \log (kd_{50}^{\ 3}/\nu) + b_3 \log (U_*/kd_{50}^{\ 2})] \log [VS/k(d_{50})^2$$

$$- V_{cr}S/k(d_{50})^2] \qquad (14)$$

where: $\omega = (g/18)(\rho_s - \rho_1)(\mu)\ d_{50}^{\ 2} = kd_{50}^{\ 2}$ (Stokes settling equation)

g = acceleration due to gravity

ρ_s = density of the particle (assumed to be 2.65)

ρ_1 = density of water

μ = dynamic viscosity

In the above, terminal velocity has been replaced with the Stokes equation (a function of median particle diameter, d_{50}). No particle sizes computed from the 1976 data on the MB-NFFC watershed were too large to settle according to Stokes Law. Should larger particles be encountered, similar replacement of ω with the transitional or turbulent settling equations could be performed.

Two unknowns are present in the two equations; d_{50} and concentration. Equating $\log C_t$ for the two equations will allow for solving for d_{50}, and subsequently for concentration.

Expanding and collecting terms in Yang's equation:

$$\log C_t = \alpha_1 + 3a_2 \log d_{50} - 2a_3 \log d_{50} + [\beta_1 + 3b_2 \log d_{50} - 2b_3 \log d_{50}] [\gamma_1 - 2 \log d_{50}] \quad (15)$$

where:
$$\alpha_1 = a_1 + a_2 \log k - a_2 \log \nu + a_3 \log U_* - a_3 \log k$$
$$\beta_1 = b_1 + b_2 \log k - b_2 \log \nu + b_3 \log U_* - b_3 \log k$$
$$\gamma_1 = \log (VS - V_{cr}S) - \log k$$

The final form of Yang's equation is:

$$\log C_t = \phi_2 \log^2 d_{50} + \phi_1 \log d_{50} + \phi_0 \quad (16)$$

where:
$$\phi_1 = 3a_2 - 2a_3 - 2\beta_1 + 3b_2\gamma_1 - 2b_3\gamma_1$$
$$\phi_2 = 4b_3 - 6b_2$$
$$\phi_0 = \alpha_1 + \beta_1\gamma_1$$

Equivalencing equations (13) and (16) yields a quadratic:

$$\phi_2 \log^2 d_{50} + (\phi_1 - \theta_1) \log d_{50} + (\phi_0 - \log \theta_0 - \log T) = 0 \quad (17)$$

and solving for $\log d_{50}$ gives:

$$\log d_{50} = \frac{-(\phi_1 - \theta_1) + \sqrt{(\phi_1 - \theta_1)^2 - 4(\phi_2)(\phi_0 - \log\theta - \log T)}}{2\phi_2} = Z \quad (18)$$

$$d_{50} = 10^{[Z]}$$

Calibration check

The 1976 flow and turbidity data were again used to check the accuracy of the equivalenced equations for predicting suspended sediment concentration. For each data point, d_{50} was computed using equation (18) and concentration was subsequently computed from either equation (13) or (16).

Figure 7 shows the log-log plot of computed concentrations versus the observed concentrations when the coefficients for Yang's equation for all the streams were used. As can be seen, the correlation has been significantly improved ($r = .974$) over the correlation obtained from calibration of Yang's equation alone ($r = .761$). Part of this improvement is due to the fact that the median particle diameter in all cases (calibration included) was computed from equation (12), so the d_{50} value has essentially been regressed against a function of itself. It is not known whether that alone would account for such an improvement in prediction capability. It also appears that the fit is best for those concentrations between 10 and 100 mg/l. This is probably due to the fact that 22 of the 33 calibration data points fell between those values, statistically biasing the calibration fit. Similar plots of computed versus observed concentration using the calibration coefficients for Yang's equation for the two stream groupings are shown in Figure 8 and 9. Correlation coefficients improved only slightly from the calibration phase. A listing of computed and observed concentrations as plotted may be found in Appendix E.

Three of the 1976 data points resulted in a negative value under the radical sign of equation (18). Acceptable results were obtained by assuming the value under the radical in those instances to be zero.

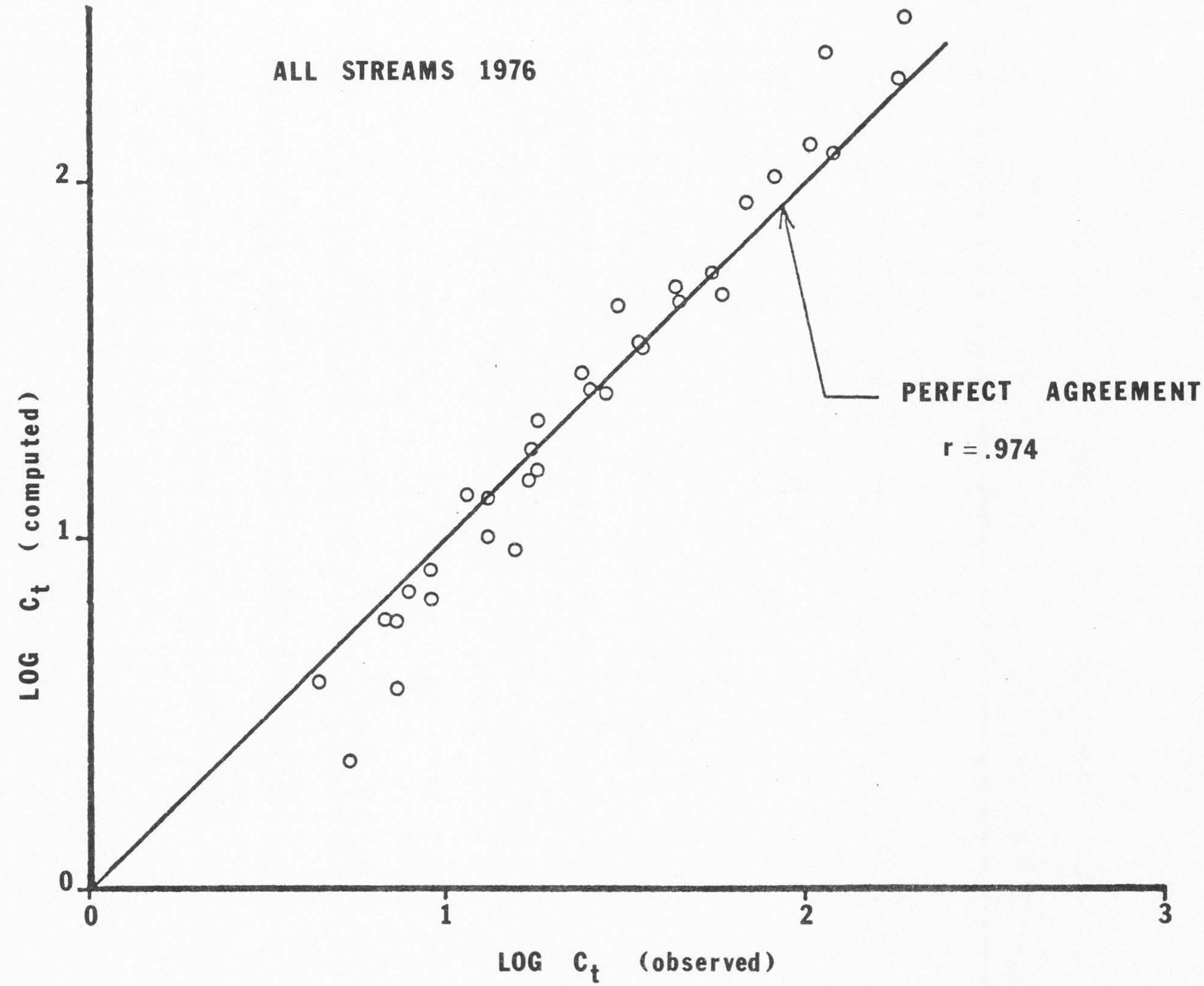

Figure 7. Computed concentrations using the equivalenced equation (18) versus observed concentration on the MB-NFFC watershed. Coefficients for all streams were used in the computations (See Table 8).

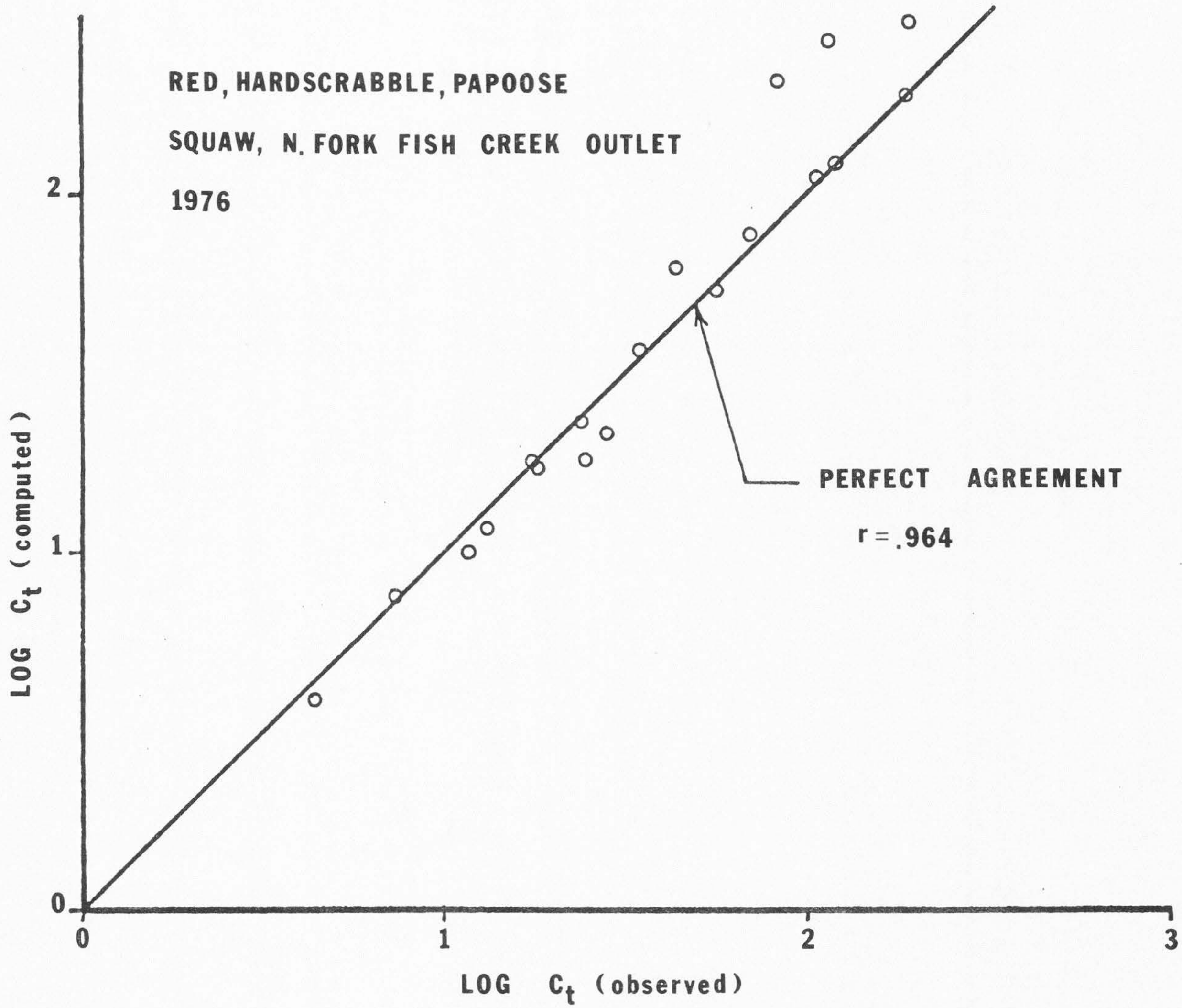

Figure 8. Computed concentrations using the equivalenced equation (18) versus observed concentration for the lower stations on the MB-NFFC watershed.

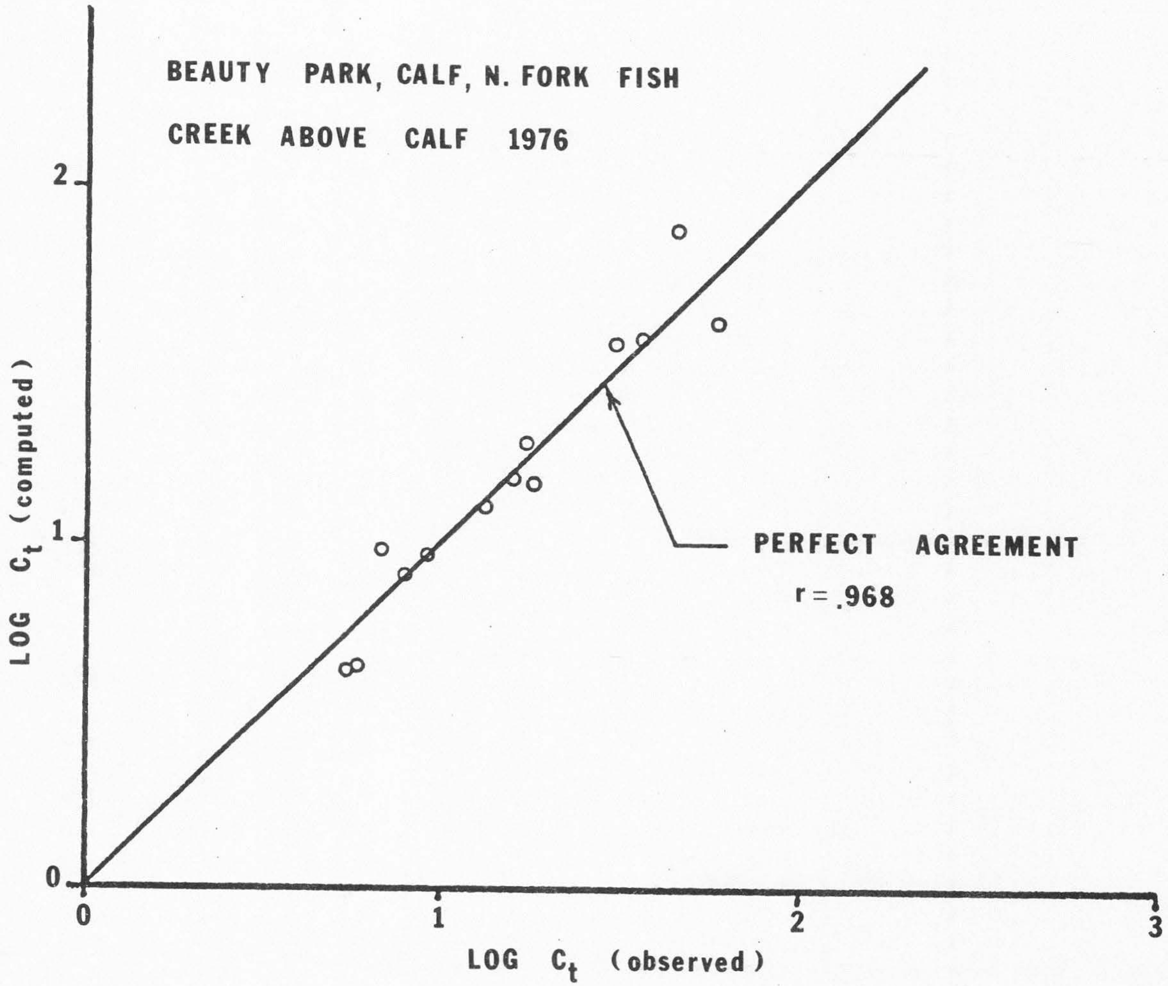

Figure 9. Computed concentrations using the equivalenced equation (18) versus observed concentration for the lower stations on the MB-NFFC watershed.

Each streamflow parameter (velocity, depth, slope, water temperature) and turbidity were altered individually to determine the behavior of each parameter input into the equation. Coefficients used in equation (18) were those derived for all streams on the MB-NFFC watershed (see Table 8). Some very general observations follow:

1) As slope and depth increase, so also does computed median particle diameter and computed suspended sediment concentration. This is as expected. The effects of these parameters on computed median particle size is somewhat greater than on computed concentration.

2) As temperature and velocity increase, computed median particle size and concentration decreases only slightly. The unexpected effect of velocity may be a statistical phenomenon due to the fact that in calibration of Yang's equation, data from the upper stream stations on the MB-NFFC watershed do indeed exhibit the lowest sediment production. The effects of slope and depth as outlined in 1) above appear to counteract this unexpected effect of velocity in prediction of suspended sediment concentration.

3) An alteration in turbidity influences suspended sediment concentration more than any of the other factors. As turbidity increases, concentration increases. No effect on computed median particle size due to turbidity can be assumed because the relationship relating median particle size, concentration, and turbidity involves two unknowns -- median particle size and concentration.

Independent Data Verification

Streamflow and turbidity data taken on the eight streams on the MB-NFFC watershed during the summer field season of 1977 were used in equation (18) and the median particle diameter and concentration computed. The coefficients for all streams were used in Yang's equation, along with the calibration V_{cr} value. Figure 10 shows the results of those computations graphically. The actual and computed data appears in Appendix E. A correlation coefficient of .818 was obtained. It

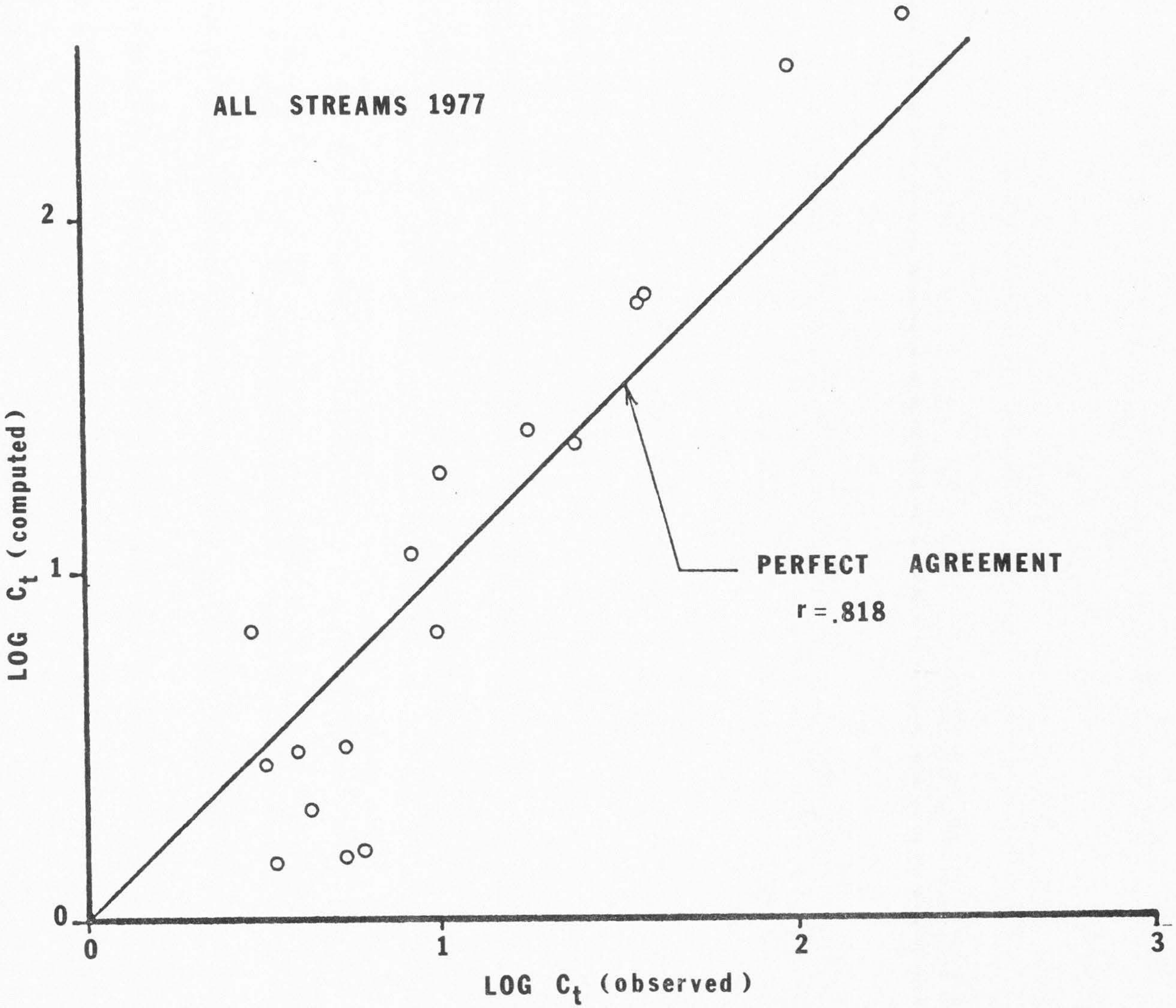

Figure 10. Computed versus observed suspended sediment concentrations for the independent 1977 field data on the MB-NFFC watershed.

should be noted that the year 1977 was an extremely dry year. This had two major effects upon the quantity and quality of verification data. First, it drastically reduced the amount of verification data. Both Red and Hardscrabble Creeks dried up completely by mid-July. In addition, the flow velocities on most of the streams dropped below the V_{cr} that had been determined in calibration of Yang's equation using the 1976 data for all streams. This resulted in a negative 'effective unit stream power' ($VS-V_{cr}S$) so the log value could not be computed and the data points were discarded.

The concentrations encountered during the 1977 field season were generally lower (due to lower flows for transport) than those encountered during 1976 for which the calibration of Yang's equation was performed.

Grassy (1943) found the Coefficient of Fineness to show considerable random fluctuation between values of about 0.5 and 2.5 on the Enoree River near Greenville, South Caroline during normal stage flow conditions. Such random fluctuations may account in part for the lack of fit of the independently predicted versus the observed 1977 data for the eight streams on the MB-NFFC watershed.

SUMMARY AND CONCLUSIONS

The effect of particle size distribution of suspended sediment on turbidity estimates of concentration has been established in a relative rather than absolute sense. Characteristics of the suspended material such as specific weight, shape, color, and refractive index were not incorporated in the analysis and no doubt contributed in part to the lack of fit of the predictive equation relating particle size distribution to the Coefficient of Fineness. Laboratory technique and instrumentation may also have been sources of error. Nevertheless, optical methods for estimating particle sizes in dilute suspensions continue to show definite promise.

The effect of particle size distribution of suspended sediment on the turbidity-concentration relationship for stream-bank materials on the Moccasin Basin-North Fork Fish Creek watershed may be described by an equation of the form:

$$C_t/T = \theta_0 \, (d_{50})^{\theta_1}$$

where:
- C_t = suspended sediment concentration in mg/l
- T = turbidity in NTU's
- d_{50} = median particle diameter of the suspended sediment
- θ_0, θ_1 = coefficients

The correlation coefficient of the relationship is $r = .748$. Generally as the median particle diameter in suspension increases, so also does the Coefficient of Fineness (C_t/T). This means that a lower turbidity accompanies a given concentration of relatively coarse particles than accompanies the same concentration of fine particles.

The utility of the derived equation becomes apparent when one recalls that the hydraulic flow conditions of a stream are also intimately related to the particle size of sediment transported by it. A method has been presented for combining a hydraulic transport equation with the above derived turbidity--particle size--concentration relationship to arrive at reasonable estimates of concentration given flow data and turbidity measure only. The particle size distribution of the suspended sediment is the link between what a stream under certain flow conditions can carry, and what a turbidity measure indicates is being carried. This 'Hydraulic Flow--Optical Measure' relationship may be regarded as a new and simple approach for getting acceptable suspended sediment information without the added time, effort, and equipment required by gravimetric analyses.

Conversely, suspended sediment concentration and turbidity data may give a good relative estimate of how particle sizes carried in suspension change over varied flow conditions for a stream. Such information may be useful in determining the activation of new sediment source areas. Should it become apparent that higher concentrations of a generally different particle size are in transport, upstream observations may reveal the source of this change. This information may also give a general indication of the extent to which sediment introduced to a stream channel during a construction project will be flushed on through the stream reach system immediately below the project.

Because of the statistical nature of the predictive equation used in this study, it is felt that the coefficients determined for its use are applicable on a regional basis at most, where stream flow hydraulics, sediment availability, and sediment transport mechanics are similar. The coefficients determined for a high mountain watershed (as in this study) will not be applicable for use in the equivalenced equations in the midwest. Also it is not certain how the technique will perform for short term flood events. For instance, Grassy (1943) found Coefficient of Fineness to reach a maximum early in the rising stages of a flood, rather than at the time of maximum discharge, as this technique would predict.

Possible Future Research

A vast amount of work is yet to be done if the 'Hydraulic Flow--Optical Measure' correlation is to be clearly defined. The effect of other suspended sediment characteristics on the turbidity-suspended sediment relationship need to be investigated. Laboratory techniques for handling dilute suspensions and measuring suspension characteristics, concentrations, and turbidity need to be further refined.

The possible use of other suspended sediment transport equations in conjunction with the Coefficient of Fineness--particle size distribution equation derived in this study, in estimating suspended sediment concentration, should be investigated. The advent of quantifying suspended sediment concentration more quickly and easily may justify the effort required.

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APPENDICES

APPENDIX A

1976 Water Quality Data

Appendix A

1976 Water Quality Data

Table 9 Streamflow and water quality data collected on the MB-NFFC watershed during the summer of 1976.

Stream	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Turbidity (NTU)	Temp (°C)	Electrical Conductivity (μm/cm)	Total Dissolved Solids (mg/l)
N. Fork Fish Creek Outlet	62576	124.40	57.5	18.0	9.1	136.2	98.0
	62776	111.80	35.5	13.0	10.8	143.8	102.0
	71176	58.80	13.5	6.2	16.3	105.3	165.0
	72076	29.90	8.0	5.6	14.7	137.8	39.0
	80476	22.80	10.5	6.4	14.9	164.4	146.0
	81476	13.30	7.5	3.5	18.2	156.1	177.0
	83176	9.50	4.0	3.0	17.5	153.0	155.0
Red Creek Outlet	61076	6.10	100.0	55.0	9.2	203.5	197.5
	61176	5.60	75.0	43.0	7.7	221.8	141.0
	62476	5.10	72.5	39.0	14.3	238.0	141.0
	62776	3.30	35.0	28.0	16.9	269.0	133.0
	71176	0.50	11.5	8.7	19.4	322.0	218.0
	72076	0.40	2.5	3.3	18.0	270.0	207.0
	81476	0.30	2.0	2.5	20.2	322.8	225.0
	83176	0.10	1.5	2.2	17.0	344.0	207.0
Squaw Creek Outlet	61276	23.20	109.5	31.0	5.0	192.5	109.0
	62576	18.40	84.5	24.0	9.2	272.4	33.0
	62876	14.40	45.0	15.0	13.8	256.0	25.0
	71176	7.60	26.0	9.7	16.5	218.0	128.0
	72076	4.70	12.0	5.9	13.3	228.0	165.0
	80476	3.50	12.0	6.8	12.7	325.0	162.0
	81476	3.10	4.0	2.8	13.8	250.0	230.0
	83176	1.80	2.5	2.9	15.5	266.0	152.0
Hardscrabble Creek Outlet	61076	4.75	119.0	49.0	11.2	230.0	140.5
	62476	3.30	71.5	23.0	10.0	273.0	150.0
	62776	2.10	25.0	10.0	11.2	286.0	158.0

Table 9 continued

Stream	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Turbidity (NTU)	Temp (°C)	Electrical Conductivity (µm/cm)	Total Dissolved Solids (mg/l)
Hardscrabble Creek Outlet	71076	0.45	4.5	2.4	23.7	210.0	165.0
	71976	0.43	18.0	6.5	15.7	287.0	224.0
	73176	0.32	2.5	2.5	17.4	259.0	191.0
	81476	0.10	1.5	1.3	18.9	356.0	207.0
	83176	0.10	0.5	1.1	20.0	368.0	267.0
Beauty Park Creek Outlet	62376	13.90	13.5	4.5	3.8	109.0	68.7
	62676	9.34	8.0	3.7	7.1	123.7	25.0
	70976	3.70	5.5	2.3	21.1	117.5	100.0
	71976	2.23	7.0	3.4	13.1	131.0	99.0
	73176	1.51	9.5	4.3	18.7	150.0	125.0
	81576	0.84	3.5	2.0	11.2	162.0	182.0
	90176	0.45	1.0	2.0	11.2	169.0	175.0
Calf Creek Outlet	62376	28.96	60.5	14.0	4.9	91.4	87.0
	62676	16.04	36.5	11.0	8.8	94.5	97.0
	70976	13.20	18.5	6.3	10.4	67.0	74.0
	71376	8.35	16.0	4.5	13.4	79.0	16.0
	73076	3.70	6.0	2.7	10.5	100.0	27.0
	81576	2.10	2.0	1.9	9.8	107.6	63.0
	83176	1.60	15.0	12.0	16.2	110.0	60.0
N. Fork Fish Creek above Calf Creek	62376	88.20	31.5	14.0	8.0	67.0	75.0
	62676	83.25	46.0	14.0	11.1	78.8	17.0
	70976	44.20	17.5	6.1	17.8	65.0	80.0
	71376	28.65	9.5	3.6	17.7	71.0	56.0
	73076	11.20	3.0	2.5	12.9	90.0	74.0
	81576	6.40	2.5	2.0	11.7	72.0	87.0
	83176	4.50	2.0	2.3	16.2	85.0	118.0
Papoose Creek Outlet	61276	16.35	199.0	59.0	4.4	177.8	125.0
	62576	13.50	190.0	44.0	8.4	214.3	129.0

Table 9 continued

Stream	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Turbidity (NTU)	Temp (^oC)	Electrical Conductivity (µm/cm)	Total Dissolved Solids (mg/l)
Papoose Creek Outlet	62876	8.70	125.0	29.0	13.0	205.0	110.0
	71176	4.10	29.0	9.9	16.1	176.0	194.0
	72076	2.60	18.5	8.4	13.0	247.0	182.0
	80376	1.75	8.5	4.8	14.2	248.0	190.0
	81476	0.99	7.0	5.8	13.0	282.0	198.0
	83176	0.90	17.5	12.0	18.0	287.0	196.0

APPENDIX B

Laboratory Data

Appendix B

Laboratory Data

Table 10 Particle size distribution and Coefficient of Fineness characteristics of stream bank materials on the MB-NFFC watershed.

Stream	Sample	Percent Sand	Percent Silt	Percent Clay	Median Particle Diameter (cm)	Percent Volatile Matter	Color	Coefficient of Fineness (mg/l per NTU)	r^2
Papoose	1	29.0	28.1	42.8	.00057	6.22	10YR5/4	2.632	.982
	2	35.0	20.9	44.1	.00053	6.01	10YR3/3	3.367	.989
	3	34.5	27.9	37.6	.00130	6.52	10YR4.5/4	4.081	.981
	4	33.5	26.5	40.0	.00062	8.05	7.5YR5.5/4	3.029	.992
	5	44.5	24.3	31.2	.00310	9.29	10YR5/4	3.979	.982
Squaw	1	53.5	22.5	24.0	.00760	13.28	10YR3/2.5	5.712	.997
	2	43.5	24.3	32.2	.00325	5.43	7.5YR5/5	3.373	.953
	3	44.5	23.5	32.0	.00330	5.85	7.5YR4/6	4.367	.985
	4	50.5	19.5	30.0	.00520	8.75	7.5YR4.5/6	4.040	.990
	5	40.8	27.4	31.8	.00210	8.53	7.5YR4.5/6	4.445	.994
N. Fork above Calf	1	50.8	20.4	28.8	.00540	10.74	10YR4/3	5.191	.997
	2	47.5	21.5	31.0	.00420	7.90	10YR3/3	4.905	.957
	3	46.4	22.9	30.7	.00400	5.73	10YR4.5/4	5.179	.976
	4	55.0	18.4	26.6	.00770	7.83	10YR5/4	5.148	.993
	5	49.8	21.2	29.0	.00480	11.24	10YR2/2	8.204	.999
N. Fork Outlet	1	32.7	27.3	40.0	.00046	6.74	2.5Y6.5/2	3.417	.999
	2	46.6	25.2	28.2	.00042	5.05	10YR4/3	5.729	.994
	3	37.5	32.0	30.5	.00245	6.66	10YR4/3	4.679	.985
	4	48.0	24.2	27.8	.00460	10.26	10YR4/4	5.915	.989
	5	39.8	30.0	30.2	.00220	7.25	10YR5/3.5	4.252	.980
Hardscrabble		36.2	24.7	39.1	.00070	7.92	10YR4/3	3.037	.956
	2	34.7	26.3	39.0	.00064	8.41	10YR4.5/4	3.777	.998
	3	32.5	24.5	43.0	.00042	6.85	10YR5.5/4	3.449	.999
	4	32.0	28.8	39.2	.00054	8.46	10YR5.5/4	3.530	.995
	5	39.1	25.7	35.2	.00125	7.36	7.5YR5/6	3.619	.980

Table 10 continued

Stream	Sample	Percent Sand	Percent Silt	Percent Clay	Median Particle Diameter (cm)	Percent Volatile Matter	Color	Coefficient of Fineness (mg/l per NTU)	r^2
Calf	1	61.0	14.3	24.7	.01100	8.58	10YR3/3	5.742	.997
	2	49.5	19.8	30.7	.00470	8.29	10YR5/4	4.080	.992
	3	64.2	12.6	23.2	.01300	10.19	10YR3/4	5.996	.996
	4	54.7	18.0	27.3	.00670	9.33	10YR4/3	7.146	.996
	5	57.2	17.4	25.4	.00730	12.26	10YR3/3	6.778	.993
Red	1	49.0	20.9	30.1	.00450	10.05	10YR5/4	4.409	.961
	2	29.0	32.8	38.2	.00050	7.21	10YR6.5/3	3.267	.991
	3								
	4	40.0	24.3	35.7	.00130	7.52	10YR6/3	2.876	.966
	5	42.3	31.9	25.8	.00370	6.59	7.5YR5/5	3.894	.999
Beauty Park	1	48.0	25.4	26.6	.00460	12.07	10YR2.5/2	6.466	.999
	2	56.0	17.8	26.2	.00680	10.88	10YR3/4	5.508	.967
	3	49.5	20.9	29.6	.00480	7.39	10YR3/2	6.783	.993
	4	55.0	20.0	25.0	.00660	8.22	10YR3/3	7.333	.983
	5	56.0	19.4	24.6	.00630	12.54	10YR3/4	6.933	.996

Table 11 a-h Turbidity and suspended sediment data for the stream bank materials on the MB-NFFC watershed.

Table 11 a

Stream Sample		Dilution Factor	Suspended Sediment Concentration (mg/l)	Turbidity (NTU)
N. Fork Fish Outlet	1	0	2380.00	700.00
		2	1232.00	350.00
		4	575.00	175.00
		10	241.00	70.00
		20	122.00	35.00
		40	54.00	17.80
		100	26.40	7.50
	2	0	2696.00	482.00
		2	1478.00	241.00
		4	744.00	120.00
		10	300.00	48.20
		20	154.00	24.70
		40	73.20	13.80
		100	32.60	5.13
	3	0	2736.00	606.00
		2	1600.00	303.00
		4	725.00	151.00
		10	321.00	60.60
		20	147.00	30.30
		40	79.30	15.50
		100	30.90	6.30
	4	0	2660.00	462.00
		2	1525.00	231.00
		4	646.00	115.00
		10	290.00	46.20
		20	152.00	24.00
		40	65.90	12.70
		100	31.60	4.86
	5	0	2541.00	624.00
		2	1491.00	312.00
		4	769.00	156.00
		10	296.00	62.40
		20	148.00	31.20
		40	67.40	17.20
		100	30.40	6.93

Table 11b

Stream Sample		Dilution Factor	Suspended Sediment Concentration (mg/l)	Turbidity (NTU)
Hardscrabble Outlet	1	0	2378.00	834.00
		2	1523.00	417.00
		4	715.00	208.00
		10	304.00	83.40
		20	147.00	41.70
		40	81.80	22.80
		100	42.20	10.80
	2	0	2847.00	764.00
		2	1515.00	382.00
		4	735.00	191.00
		10	294.00	76.40
		20	139.00	38.20
		40	68.10	20.70
		100	31.90	8.83
	3	0	2900.00	840.00
		2	1446.00	420.00
		4	718.00	210.00
		10	292.00	84.00
		20	146.00	42.00
		40	77.60	22.20
		100	30.50	9.30
	4	0	2417.00	700.00
		2	1315.00	350.00
		4	670.00	175.00
		10	259.00	70.00
		20	127.00	35.00
		40	65.50	18.70
		100	27.00	7.63
	5	0	2633.00	760.00
		2	1551.00	380.00
		4	790.00	190.00
		10	303.00	76.00
		20	159.00	38.00
		40	72.00	18.00
		100	33.70	7.56

Table 11 c

Stream Sample		Dilution Factor	Suspended Sediment Concentration (mg/l)	Turbidity (NTU)
N. Fork Fish Creek above Calf	1	0	2035.00	398.00
		2	1074.00	199.00
		4	550.00	99.50
		10	223.00	39.80
		20	114.00	20.00
		40	50.60	8.35
		100	24.60	4.23
	2	0	1961.00	425.00
		2	1198.00	212.00
		4	679.00	106.00
		10	262.00	42.50
		20	112.00	23.50
		40	54.80	12.20
		100	31.60	4.40
	3	0	2188.00	443.00
		2	1330.00	221.00
		4	630.00	111.00
		10	240.00	44.30
		20	119.00	24.50
		40	63.50	13.00
		100	28.10	4.90
	4	0	2157.00	430.00
		2	1200.00	215.00
		4	581.00	107.00
		10	242.00	43.00
		20	121.00	22.20
		40	62.60	9.66
		100	26.30	4.58
	5	0	2423.00	295.00
		2	1223.00	147.00
		4	574.00	73.70
		10	214.00	29.50
		20	116.00	15.50
		40	55.20	6.16
		100	22.30	2.96

Table 11 d

Stream Sample		Dilution Factor	Suspended Sediment Concentration (mg/l)	Turbidity (NTU)
Calf Creek Outlet	1	0	1825.00	320.00
		2	963.00	160.00
		4	419.00	80.00
		10	190.00	32.00
		20	88.20	16.20
		40	54.70	6.58
		100	14.80	3.40
	2	0	2127.00	534.00
		2	1147.00	267.00
		4	628.00	133.00
		10	233.00	53.40
		20	120.00	26.70
		40	55.50	14.70
		100	22.30	6.40
	3	0	1494.00	253.00
		2	773.00	126.00
		4	429.00	63.20
		10	167.00	25.30
		20	86.90	13.00
		40	34.40	5.50
		100	12.10	2.56
	4	0	2178.00	310.00
		2	1153.00	155.00
		4	609.00	77.50
		10	236.00	31.00
		20	108.00	16.80
		40	54.30	6.73
		100	25.30	3.51
	5	0	2122.00	320.00
		2	1184.00	160.00
		4	532.00	80.00
		10	223.00	32.00
		20	85.50	15.30
		40	56.70	7.40
		100	20.20	3.68

Table 11 e

Stream Sample		Dilution Factor	Suspended Sediment Concentration (mg/l)	Turbidity (NTU)
Beauty Park Creek Outlet	1	0	2501.00	388.00
		2	1261.00	194.00
		4	629.00	97.00
		10	291.00	38.80
		20	143.00	21.20
		40	63.90	8.80
		100	23.60	4.30
	2	0	1756.00	337.00
		2	1089.00	168.00
		4	519.00	84.20
		10	218.00	33.70
		20	122.00	17.00
		40	54.80	7.13
		100	20.00	3.70
	3	0	2517.00	380.00
		2	1405.00	190.00
		4	645.00	95.00
		10	286.00	38.00
		20	135.00	21.00
		40	68.40	8.66
		100	26.20	4.26
	4	0	2148.00	305.00
		2	1251.00	152.00
		4	628.00	76.20
		10	250.00	30.50
		20	120.00	15.30
		40	62.60	6.70
		100	22.60	3.25
	5	0	2107.00	310.00
		2	1143.00	155.00
		4	559.00	77.50
		10	236.00	31.00
		20	113.00	14.50
		40	52.10	6.86
		100	20.30	3.36

Table 11f

Stream Sample		Dilution Factor	Suspended Sediment Concentration (mg/l)	Turbidity (NTU)
Squaw Creek	1	0	1912.00	333.00
		2	957.00	166.00
		4	417.00	83.20
		10	211.00	33.30
		20	80.80	18.20
		40	33.70	7.30
		100	22.20	3.40
	2	0	2269.00	720.00
		2	1468.00	360.00
		4	727.00	180.00
		10	273.00	72.00
		20	131.00	36.00
		40	70.70	19.30
		100	28.10	7.33
	3	0	2329.00	554.00
		2	1361.00	277.00
		4	653.00	138.00
		10	264.00	55.40
		20	129.00	27.70
		40	65.50	14.50
		100	33.30	5.85
	4	0	2289.00	584.00
		2	1296.00	292.00
		4	628.00	146.00
		10	264.00	58.40
		20	122.00	29.20
		40	60.70	14.50
		100	24.30	6.51
	5	0	2692.00	620.00
		2	1497.00	310.00
		4	703.00	155.00
		10	287.00	62.00
		20	147.00	31.00
		40	65.60	15.80
		100	30.10	6.71

Table 11 g

Stream Sample	Dilution Factor		Suspended Sediment Concentration (mg/l)	Turbidity (NTU)
Papoose Outlet	1	0	2951.00	1168.00
		2	1720.00	584.00
		4	886.00	292.00
		10	333.00	117.00
		20	171.00	58.40
		40	84.70	29.20
		100	57.00	14.20
	2	0	2479.00	760.00
		2	1420.00	380.00
		4	669.00	190.00
		10	280.00	76.00
		20	135.00	38.00
		40	72.00	20.70
		100	25.10	8.26
	3	0	2848.00	726.00
		2	1623.00	363.00
		4	916.00	181.00
		10	294.00	72.60
		20	150.00	36.30
		40	74.30	18.80
		100	32.30	7.70
	4	0	3044.00	1032.00
		2	1698.00	516.00
		4	834.00	258.00
		10	327.00	103.00
		20	158.00	51.60
		40	83.50	25.80
		100	42.40	11.00
	5	0	2367.00	620.00
		2	1374.00	310.00
		4	726.00	155.00
		10	272.00	62.00
		20	136.00	31.00
		40	53.90	15.20
		100	26.70	6.00

Table 11 h

Stream Sample		Dilution Factor	Suspended Sediment Concentration (mg/l)	Turbidity (NTU)
Red Creek Outlet	1	0	1935.00	465.00
		2	1240.00	232.00
		4	524.00	116.00
		10	248.00	46.50
		20	26.30	7.30
		40	116.00	25.30
		100	59.40	14.60
	2	0	2393.00	754.00
		2	1339.00	377.00
		4	679.00	188.00
		10	254.00	75.40
		20	126.00	37.70
		40	65.20	19.70
		100	28.40	7.48
	3	0	2337.00	764.00
		2	1409.00	382.00
		4	668.00	191.00
		10	256.00	76.40
		20	141.00	38.20
		40	75.40	19.30
		100	27.60	8.30
	4	0	2271.00	836.00
		2	1394.00	418.00
		4	730.00	209.00
		10	280.00	83.60
		20	144.00	41.80
		40	71.20	21.30
		100	31.30	9.36
	5	0	2662.00	690.00
		2	1370.00	345.00
		4	715.00	172.00
		10	278.00	69.00
		20	134.00	34.50
		40	73.20	17.30
		100	26.90	7.58

APPENDIX C

Calibration of Yang's Equation

Calibration of Yang's Equation

The Calibration Program

On the following pages appears the computer program for calibrating Yang's equation given actual field suspended sediment concentration and flow data. Once all data has been read in, the operator merely changes the limits of the 'critical velocity' (V_{cr}) and the step size and the program performs all calculations for determining the effective unit stream power, and ultimately performs a multiple linear regression on the data. These steps are repeated until the best correlation coefficient is achieved. Operation of the program may be performed by following the instructions below.

Load Program

Enter data as shown at the end of the program listing.

RUN Program	COMMAND:	"NUMBER OF DATA POINTS?"
	User Enters:	Number of data points for the calibration
	COMMAND:	INPUT "LIMITS OF CRITICAL VELOCITY -- STEP SIZE?"
	User Enters:	The estimated lower limit of V_{cr}, the estimated upper limit of V_{cr}, the step size in traveling from the lower to the upper limit in the trial and error procedure.

If particles of between .012 and 0.43 centimeters in diameter are encountered within the program, input of data from Fair, Geyer, and Okun (1968) is required, as shown below.

The program computes the 'diameter term' required for Figure 25-3 of Fair, Geyer, and Okun (1968) and lists it:

STATEMENT: THE DIAMETER TERM FOR FIGURE 25-3 IS ####.##

The operator uses the 'diameter term' in Figure 25-3 to determine the velocity term required by the program:

COMMAND: INPUT "VELOCITY TERM FROM 25-3?"

User Enters: The velocity term from Figure 25-3 of Fair, Geyer, and Okun (1968)

Program Output

The program echoes all input parameters in tabular forms as shown in Table 12 for the 1976 data. Included in the table are the components of the 'effective unit stream power' term in Yang's equation (VS/w and $V_{cr}S/W$).

The program asks for information so that it may perform the multiple linear regression on the input and computed data.

COMMAND: INPUT "M, N?"

User Enters: Number of independent variables (5 for Yang's equation) in the multiple linear regression, number of data points.

Program Output

The program prints out the entire 'sums of squares' regression table along with the coefficient of determination (r^2) and multiple correlation (r). Also printed is the 'critical velocity' (V_{cr}) for the particular calibration run.

The program then asks:

QUESTION: "DO YOU WISH TO ESTIMATE VALUES OF 'Y' FROM THE REGRESSION CURVE?" (1=YES, 0=NO)

User Enters: Either 1 or 0

If 0 is entered, V_{cr} is incremented by one step-size and program computations begin again.

Figure 11 The computer program used in calibration of Yang's equation from actual field data (BASIC language).

```
10 SELECT PRINT 211(156)
20 DIM V(60),D5(60),C(60),U1(60),U2(60),U3(60),D0(60),S(60),V1(6
0),Q1(60),Q2(60),X(10),W(60),U5(60),X(10),D(7),E(6),A(6,7),T(100
),F(60),T5(60)
30 INPUT "NUMBER OF DATA POINTS",N
40 PRINTUSING 60
50 PRINTUSING 70
60% FLOW CONCENTRATION TURBIDITY  VELOCITY  SLOPE    d50
DEPTH   TEMP(F)      VISCOSITY          SPECIFIC   V*S/W
Vcr*S/W
70% (CFS)    (MG/L)      (NTU)     (CM/SEC)              (CM)
(CM)     (F)      (KINEMATIC) (ABSOLUTE)  GRAVITY
80 PRINT
90 INPUT "LIMITS OF CRITICAL VELOCITY--STEP SIZE",Z1,Z2,Z3
100 FOR Z = Z1 TO Z2 STEP Z3
110 H=1/LOG(10): G=980.6
120 FOR I= 1 TO N: READ F(I): NEXT I
130 FOR I=1 TO N: READ C(I): NEXT I
140 FOR I=1 TO N: READ T(I): NEXT I
150 FOR I=1 TO N: READ V(I): NEXT I
160 FOR I=1 TO N: READ S(I): NEXT I
170 FOR I=1 TO N: READ D5(I):NEXT I
180 FOR I=1 TO N: READ D0(I): NEXT I
190 FOR I=1 TO N: READ T5(I): NEXT I
200 FOR I=1 TO N: READ U1(I): NEXT I
210 FOR I=1 TO N: READ U2(I): NEXT I
220 FOR I=1 TO N: READ U3(I): NEXT I
230 FOR I=1 TO N
240 IF D5(I)!=.012 THEN 360
250 IF D5(I)10.43 THEN 390
260 D2=(G*(2.65-1)/U1(I)½2)½.333333*D5(I)
270 PRINTUSING 280,D2
280% THE DIAMETER TERM FOR FIGURE 25-3 IS ##.####
290 INPUT " VELOCITY TERM FROM 25-3",V2
300 REM TRANSITIONAL SETTLING EQUATION
310 W(I)=V2*(G*(2.65-1)*U1(I))½.3333333
320 REM REYNOLDS NUMBER COMPUTED
330 R=D5(I)*W(I)/U1(I)
340 GOTO 410
350 REM LAMINAR SETTLING EQUATION (STOKES LAW)
360 W(I)=(G/18)*((2.65-U3(I))/U2(I))*D5(I)½2
370 GOTO 330
380 REM TURBULENT SETTLING EQUATION
390 W(I)=1.82*((2.65-U3(I))/(U3(I))*D5(I)*G)½.5
400 GOTO 330
410 TO=   G *DO(I)*S(I)
420 U5(I)=SQR(T0)
430 IF (U5(I)*D5(I)/U1(I)) 1=70 THEN 460
440 V1(I)=Z
450 GOTO 470
460 V1(I)=2.05*W(I)
```

Figure 11 continued

```
490 Q1(I)=V(I)*S(I)/W(I)
500 Q2(I)=V1(I)*S(I)/W(I)
510 PRINTUSING 530,F(I),C(I),T(I),V(I),S(I),D5(I),D0(I),T5(I),U1
(I),U2(I),U3(I),Q1(I),Q2(I)
520% MG/L   d50(CM)  CM/SEC  SLOPE   CM  STOKES  POISE  GMS/CM3
530%###.##    ###.##       ##.##     ###.##    .#####  .#######
 ###.#    ##.#    .######     .######      .#####  ######.##  ##
####.##
540 NEXT I
550 PRINT "INPUT M,N":INPUT M,N
560 FOR I=1 TO M+2: FOR J=1 TO M+1: A(J,I)=0
570 NEXT J:D(I)=0: NEXT I
580 FOR K=1 TO N
590 X(1)=H*LOG(W(K)*D5(K)/U1(K))
600 X(2)=H*LOG(U5(K)/W(K))
610 X(3)=H*LOG(Q1(K)-Q2(K))
620 X(4)=H*LOG(W(K)*D5(K)/U1(K))*H*LOG(Q1(K)-Q2(K))
630 X(5)=H*LOG(U5(K)/W(K))*H*LOG(Q1(K)-Q2(K))
640 X(6)=H*LOG(C(K))
650 D(M+2)=D(M+2)+X(M+1)½2: D(1),A(1,M+2)=A(1,M+2)+X(M+1)
660 FOR I=1 TO M: A(I+1,1),A(1,I+1)=A(1,I+1)+X(I)
670 D(I+1),A(I+1,M+2)=A(I+1,M+2)+X(I)*X(M+1)
680 FOR J=I TO M: A(I+1,J+1),A(J+1,I+1)=A(I+1,J+1)+X(I)*X(J)
690 NEXT J: NEXT I: NEXT K
700 SELECT PRINT 005
710 A(1,1)=N
720 FOR I=2 TO M+1: E(I)=A(1,I): NEXT I
730 FOR S=1 TO M+1
740 FOR T=S TO M+1: IF A(T,S)!10 THEN 760: NEXT T
750 PRINT "NO UNIQUE SOLUTION":GOTO 1160
760 GOSUB 810
770 C=1/A(S,S): GOSUB 840
780 FOR T=1 TO M+1: IF T=S THEN 800
790 C=-A(T,S): GOSUB 850
800 NEXT T: NEXT S: GOTO 860
810 FOR J=1 TO M+2
820 B=A(S,J): A(S,J)=A(T,J): A(T,J)=B
830 NEXT J: RETURN
840 FOR J=1 TO M+2: A(S,J)=C*A(S,J): NEXT J: RETURN
850 FOR J=1 TO M+2: A(T,J)=A(T,J)+C*A(S,J): NEXT J: RETURN
860 PRINT
870 FOR T=1 TO M+1: PRINT "B(";T-1;")=";A(T,M+2): NEXT T
880 STOP :PRINT HEX(03)
890 S=0
900 FOR I=2 TO M+1: S=S+A(I,M+2)*(D(I)-E(I)*D(1)/N): NEXT I
910 T=D(M+2)-D(1)½2/N: C=T-S
920 I=N-M-1: J=S/M: K=C/I
930 PRINT : PRINT
940 PRINT " ","  REGRESSION TABLE": PRINT
950 PRINT "SOURCE","SUM OF SQ.","DEG.FREEDOM","MEAN SQ."
960 PRINT "REGRESSION",S,M,J
970 PRINT "RESIDUAL",C,I,K
980 PRINT "TOTAL",T,N-1: PRINT
990 PRINT "F=";J/K
1000 PRINT : PRINT : J=S/T
1010 PRINT "COEFFICIENT OF DETERMINATION =";J
1020 PRINT "COEFFICIENT OF MULTIPLE CORRELATION=";SQR(J)
1030 PRINT "STANDARD ERROR OF ESTIMATE=";SQR(C/I)
1040 PRINT : PRINT
1050 PRINT "CRITICAL VELOCITY IS ";Z,"CM/SEC"
1060 PRINT "DO YOU WISH TO ESTIMATE VALUES OF Y FROM THE"
1070 PRINT "REGRESSION CURVE? (1=YES,0=NO)"
1080 INPUT I: IF I=0 THEN 1140
1090 PRINT : S=A(1,M+2)
1100 FOR I=1 TO M: PRINT "COORDINATE X";I
```

Figure 11 continued

```
1110 INPUT T: S=S+A(I+1,M+2)*T: NEXT I
1120 PRINT "Y=";S: PRINT
1130 PRINT "ANOTHER POINT?": GOTO 1080
1140 RESTORE
1150 NEXT Z
1160 END

1170 DATA      FLOW DATA IN CFS
1180 DATA      SUSPENDED SEDIMENT CONCENTRATION DATA IN MG/L
1190 DATA      TURBIDITY DATA (NEPHELOMETRIC TURBIDITY UNITS)
1200 DATA      MEAN STREAMFLOW VELOCITY IN CM/SEC
1210 DATA      AVERAGE STREAM SLOPE
1220 DATA      COMPUTED MEDIAN PARTICLE SIZE USING EQUATION  IN TEXT
1230 DATA      MEAN DEPTH OF FLOW (CM)
1240 DATA      WATER TEMPERATURE IN DEGREES FARENHEIT
1250 DATA      KINEMATIC VISCOSITY IN STOKES
1260 DATA      ABSOLUTE VISCOSITY IN POISE
1270 DATA      SPECIFIC GRAVITY OF THE WATER IN GRAMS/CM3
```

Table 12 Data inputs from the MB-NFFC watershed, used for the calibration of Yang's equation.

FLOW (CFS)	CONCERNTRATION (MG/L)	TURBIDITY (NTU)	VELOCITY (CM/SEC)	SLOPE	COMPUTED d50 (CM)	DEPTH (CM)	TEMP (F)	VISCOSITY (KINEMATIC)	VISCOSITY (ABSOLUTE)	SPECIFIC GRAVITY	V*S/ ω	Vcr*S/ ω
HARDSCRABBLE CREEK												
4.75	119.00	49.00	32.66	.04240	.0001656	16.4	52.2	.012646	.012642	.99963	7100.29	1984.86
3.30	71.50	23.00	30.76	.04240	.0004736	14.6	50.0	.013101	.013097	.99973	847.08	251.42
2.10	25.00	10.00	18.74	.04240	.0001874	11.8	52.2	.012646	.012642	.99963	3181.34	1549.93
0.45	4.50	2.40	10.89	.04240	.0000551	6.7	74.7	.009285	.009282	.99740	15679.96	13145.82
0.43	18.00	6.50	9.22	.04240	.0002895	7.4	60.3	.011188	.011184	.99900	580.00	574.34
PAPOOSE CREEK												
16.35	199.00	59.00	62.19	.03250	.0006700	21.6	39.9	.015746	.015741	.99999	788.46	115.75
13.50	190.00	44.00	54.83	.03250	.0019170	18.7	47.1	.013761	.013757	.99982	74.20	12.35
8.70	125.00	29.00	47.36	.03250	.0019027	23.5	55.4	.012019	.012015	.99939	56.80	10.95
4.10	29.00	9.90	40.99	.03250	.0003680	11.2	61.0	.011074	.011071	.99894	1210.79	269.68
2.60	18.50	8.40	31.31	.03250	.0001090	12.6	55.4	.012019	.012015	.99939	11443.88	3337.03
SQUAW CREEK												
23.20	109.50	31.00	75.66	.02762	.0008150	23.6	41.0	.015413	.015408	.99998	539.27	65.07
18.40	84.50	24.00	55.70	.02762	.0008040	42.6	48.6	.013423	.013419	.99980	355.24	58.22
14.40	45.00	15.00	55.20	.02762	.0004070	23.9	56.8	.011760	.011757	.99926	1203.29	199.02
7.60	26.00	9.70	42.90	.02762	.0002520	16.6	61.7	.010963	.010960	.99888	2273.48	483.84
4.70	12.00	5.90	30.90	.02762	.0000779	14.4	55.9	.011921	.011917	.99936	18638.13	5506.99
BEAUTY PARK CREEK												
13.90	13.50	4.50	56.70	.04100	.0004070	25.9	38.8	.016094	.016090	.99998	2512.03	404.49
9.34	8.00	3.70	57.50	.04100	.0001010	24.1	44.8	.014349	.014345	.99992	36879.50	5855.82
3.70	5.50	2.30	38.00	.04100	.0001550	15.8	70.0	.009828	.009825	.99799	7079.53	1700.95
2.23	7.00	3.40	30.80	.04100	.0000820	13.3	55.6	.011986	.011983	.99937	25026.68	7418.62
1.51	9.50	4.30	32.60	.04100	.0001110	11.1	65.7	.010389	.010386	.99847	12522.69	3507.12
CALF CREEK												
28.96	60.50	14.00	98.00	.05400	.0019240	19.8	40.8	.015467	.015463	.99999	245.92	22.91
16.04	36.50	11.00	72.10	.05400	.0006250	20.3	47.8	.013590	.013586	.99983	1506.30	190.74
13.20	18.50	6.30	67.90	.05400	.0003720	18.5	50.7	.012946	.012942	.99970	3814.14	512.85
8.35	16.00	4.50	46.40	.05400	.0008390	17.1	56.1	.011888	.011885	.99935	470.44	92.56
3.70	6.00	2.70	33.70	.05400	.0001135	10.4	50.9	.012907	.012903	.99969	20273.91	5492.60

Table 12 continued

NORTH FORK FISH CREEK OUTLET												
124.40	57.50	18.00	65.80	.00628	.0005317	39.8	48.4	.013464	.013460	.99981	218.84	30.36
111.80	35.50	13.00	63.90	.00628	.0002728	36.0	51.4	.012794	.012790	.99967	767.10	109.60
58.80	13.50	6.20	47.10	.00628	.0001041	29.5	61.3	.011018	.011015	.99891	3342.51	647.92
13.30	7.50	3.50	25.20	.00628	.0000972	20.7	64.8	.010514	.010511	.99856	1956.99	709.02
NORTH FORK FISH CREEK ABOVE CALF												
88.20	31.50	14.00	84.00	.02134	.0001197	29.6	46.4	.013937	.013933	.99988	19390.77	2107.59
83.20	46.00	14.00	73.40	.02134	.0005990	32.2	52.0	.012682	.012679	.99963	615.63	76.57
44.20	17.50	6.10	61.80	.02134	.0003360	32.5	64.0	.010617	.010613	.99885	1378.27	203.61
28.65	9.50	3.60	46.40	.02134	.0002360	30.0	63.9	.010642	.010639	.99886	2102.74	413.75

APPENDIX D

The Computation Program

The Computation Program

Once the calibration coefficients for Yang's equation have been determined, the following program may be used to compute estimated suspended sediment concentrations. The program first computes median particle diameter using Equation 18 of the text, and then computes concentration in mg/l. Operation of the program may be performed by following the instructions below:

Load Program

Enter data as shown at the end of the program listing. Note that the calibration coefficients to the equations must be entered in their proper order. Refer to the program listing to determine this order if in doubt. Also, units must be consistent throughout.

RUN Program	COMMAND:	"NUMBER OF DATA POINTS?"
	User Enters:	Number of data points for which concentration is to be computed.

Program Output

The program lists in tabular form both the logarithmic (base 10) and actual computed values of median particle size and suspended sediment concentration.

Figure 12 The computer program used to compute suspended sediment concentration given turbidity and flow data (BASIC Language).

```
10 INPUT "NUMBER OF DATA POINTS", N
20 SELECT PRINT 005(156)
30 PRINT "NAME OF STREAM"
40 REM READ IN CALIBRATION COEFFICIENTS TO YANG'S EQUATION
50 READ A1,A2,A3,B1,B2,B3,V1
60 REM READ IN COEFFICIENTS TO 'CF VS. PSD' EQUATION (EQN. 7)
70 READ O1,O2
80 PRINTUSING 100
90 PRINTUSING 110
100%    COMPUTED             COMPUTED
110% LOG D50    D50     LOG C5Y    C5Y
120 FOR I=1 TO N
130 REM READ IN TURBIDITY AND FLOW DATA
140 READ T,V,S,D0,T5,U3
150 U1=60/(T5+10)*1.3101*.01: U2=60/(T5+10)*1.3097*.01
160 G=980.6: H=1/LOG(10)
170 U5=SQR(G*D0*S)
180 K=(G/18)*((2.65-U3)/U2)
190 R1=A1+(A2*H*LOG(K))-(A2*H*LOG(U1))+(A3*H*LOG(U5))-(A3*H*LOG(
K))
200 S1=B1+(B2*H*LOG(K))-(B2*H*LOG(U1))+(B3*H*LOG(U5))-(B3*H*LOG(
K))
210 X1=H*LOG((V*S)-(V1*S))-H*LOG(K)
220 P0=R1+S1*X1
230 P1=(3*A2)-(2*A3)-(2*S1)+(3*X1*B2)-(2*X1*B3)
240 P2=(4*B3)-(6*B2)
250 Z1=(P1-O2)½2
260 Z2=4*P2*(P0-H*LOG(O1)-H*LOG(T))
270 IF Z1122 THEN 290
280 D2=0:GOTO 300
290 D2=SQR(Z1-Z2)
300 D5=(-(P1-O2)+D2)/(2*P2)
310 C5=P0+P1*D5+P2*D5½2
320 C6=H*LOG(O1)+O2*D5+H*LOG(T)
330 PRINTUSING 340,D5,10½D5,C5,10½C5
340% #.### #.####### #.### ####.## ####.##      #.###
350 NEXT I
360 END

370 DATA      CALIBRATION COEFFICIENTS TO YANG'S EQUATION, CRITICAL
              VELOCITY
380 DATA      COEFFICIENTS TO THE 'COEFFICIENT OF FINENESS--PARTICLE
              SIZE DISTRIBUTION' EQUATION (θ0 and θ1 ):
390 DATA      TURBIDITY, MEAN VELOCITY, AVERAGE SLOPE, MEAN DEPTH,
              TEMPERATURE, SPECIFIC GRAVITY ( entered respectively for
              each data point).
```

NOTE: The cgs system of units is used throughout. Temperature is in degrees centigrade.

APPENDIX E

Observed and Computed Concentrations
for the MB-NFFC Watershed

Appendix E

Observed and Computed Concentrations for the MB-NFFC Watershed

Table 13 Actual and computed concentrations using the calibration coefficients for all the streams in Yang's equation. (1976 data)

ALL STREAMS ON THE MB-NFFC WATERSHED

COMPUTED MEDIAN PARTICLE DIAMETER (CM)		COMPUTED CONCENTRATION (MG/L)		ACTUAL CONCENTRATION (MG/L)	
LOG D50	D50	LOG Ct	Ct	Ct	LOG Ct
-2.526	0.0029742	2.370	234.57	119.00	2.075
-2.930	0.0011743	1.946	88.50	71.50	1.854
-3.424	0.0003761	1.469	29.44	25.00	1.397
-4.514	0.0000305	0.593	3.91	4.50	0.653
-3.533	0.0002924	1.256	18.04	18.00	1.255
-2.426	0.0037471	2.474	298.19	199.00	2.298
-2.627	0.0023601	2.299	199.49	190.00	2.278
-2.764	0.0017187	2.086	122.04	125.00	2.096
-3.644	0.0002264	1.412	25.87	29.00	1.462
-3.665	0.0002161	1.336	21.71	18.50	1.267
-2.767	0.0017064	2.114	130.23	109.50	2.039
-2.689	0.0020420	2.021	105.17	84.50	1.926
-3.186	0.0006515	1.701	50.25	45.00	1.653
-3.573	0.0002667	1.420	26.34	26.00	1.414
-3.908	0.0001234	1.126	13.37	12.00	1.079
-3.918	0.0001206	1.006	10.14	13.50	1.130
-4.213	0.0000611	0.851	7.11	8.00	0.903
-5.441	0.0000036	0.369	2.33	5.50	0.740
-4.370	0.0000426	0.778	6.00	7.00	0.845
-4.242	0.0000572	0.910	8.13	9.50	0.977
-3.128	0.0007438	1.684	48.39	60.50	1.781
-3.275	0.0005304	1.545	35.11	36.50	1.562
-3.765	0.0001714	1.188	15.42	18.50	1.267
-4.065	0.0000859	0.971	9.36	16.00	1.204
-4.806	0.0000156	0.575	3.76	6.00	0.778
-3.312	0.0004865	1.750	56.31	57.50	1.759
-3.526	0.0002974	1.559	36.22	35.50	1.550
-4.042	0.0000906	1.116	13.06	13.50	1.130
-4.481	0.0000329	0.764	5.81	7.50	0.875
-3.231	0.0005874	1.660	45.77	31.50	1.498
-3.206	0.0006216	1.666	46.39	46.00	1.662
-3.798	0.0001589	1.166	14.67	17.50	1.243
-4.257	0.0000553	0.829	6.75	9.50	0.977

Table 14 Actual and computed concentrations using the coefficients for the two stream groups (as shown) in Yang's equation. (1976 data)

BEAUTY PARK, CALF, N. FORK FISH ABOVE CALF

COMPUTED MEDIAN PARTICLE DIAMETER (CM)		COMPUTED CONCENTRATION (MG/L)		ACTUAL CONCENTRATION (MG/L)	
LOG D50	D50	LOG Ct	Ct	Ct	LOG Ct
-3.511	0.0003078	1.101	12.64	13.50	1.130
-3.993	0.0001015	0.903	8.00	8.00	0.903
-4.276	0.0000528	0.630	4.27	5.50	0.740
-3.514	0.0003059	0.979	9.53	7.00	0.845
-4.012	0.0000971	0.964	9.21	9.50	0.977
-3.345	0.0004515	1.633	43.03	60.50	1.781
-2.555	0.0027815	1.583	38.33	36.50	1.562
-3.821	0.0001508	1.175	14.96	18.50	1.267
-3.140	0.0007235	1.189	15.45	16.00	1.204
-4.495	0.0000319	0.648	4.45	6.00	0.778
-3.645	0.0002259	1.563	36.57	31.50	1.498
-2.575	0.0026593	1.814	65.28	46.00	1.662
-3.283	0.0005208	1.287	19.39	17.50	1.243
-3.686	0.0002060	0.963	9.20	9.50	0.977

PAPOOSE,SQUAW,RED,HARDSCRABBLE, N. FORK FISH OUTLET

-2.234	0.0058272	2.438	274.73	119.00	2.075
-3.154	0.0007008	1.894	78.39	71.50	1.854
-3.808	0.0001555	1.378	23.93	25.00	1.397
-4.504	0.0000312	0.595	3.93	4.50	0.653
-3.527	0.0002966	1.257	18.10	18.00	1.255
-2.371	0.0042556	2.487	307.25	199.00	2.298
-2.693	0.0020252	2.284	192.44	190.00	2.278
-2.756	0.0017531	2.088	122.61	125.00	2.096
-3.971	0.0001067	1.336	21.68	29.00	1.462
-4.084	0.0000823	1.238	17.31	18.50	1.267
-3.053	0.0008837	2.047	111.58	109.50	2.039
-1.424	0.0375973	2.319	208.54	84.50	1.926
-3.663	0.0002171	1.799	63.09	45.00	1.653
-4.579	0.0000263	1.265	18.41	26.00	1.414
-4.430	0.0000370	1.003	10.08	12.00	1.079
-3.344	0.0004520	1.743	55.34	57.50	1.759
-3.483	0.0003285	1.569	37.08	35.50	1.550
-3.794	0.0001605	1.174	14.94	13.50	1.130
-3.984	0.0001035	0.881	7.61	7.50	0.875

Table 15 Actual and computed concentrations for the independent 1977 field data on the MB-NFFC watershed.

VERIFICATION WITH MB-NFFC DATA FOR THE 1977 FIELD SEASON

COMPUTED MEDIAN PARTICLE DIAMETER (CM)		COMPUTED CONCENTRATION (MG/L)		ACTUAL CONCENTRATION (MG/L)	
LOG D50	D50	LOG Ct	Ct	Ct	LOG Ct
-3.176	0.0006662	1.782	60.62	39.40	1.595
-2.301	0.0049962	2.584	383.94	208.00	2.318
-2.552	0.0028012	2.429	269.05	99.50	1.997
-3.475	0.0003346	1.401	25.21	18.27	1.261
-4.294	0.0000507	0.454	2.85	3.25	0.511
-3.354	0.0004415	1.764	58.09	37.50	1.574
-3.879	0.0001318	1.281	19.10	10.85	1.035
-4.040	0.0000909	1.056	11.39	8.50	0.929
-3.496	0.0003184	1.365	23.22	24.50	1.389
-5.427	0.0000037	0.323	2.10	4.34	0.637
-5.685	0.0000020	0.193	1.56	5.50	0.740
-5.712	0.0000019	0.174	1.49	3.50	0.544
-4.818	0.0000151	0.503	3.18	5.50	0.740
-5.720	0.0000019	0.201	1.59	6.14	0.788
-4.299	0.0000502	0.493	3.11	4.00	0.602
-4.010	0.0000976	0.933	8.57	3.00	0.477
-4.339	0.0000458	0.833	6.82	10.00	1.000

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