LONGITUDINAL VARIATION IN SUSPENDED SEDIMENT AND TURBIDITY OF TWO UNDISTURBED STREAMS IN NORTHWESTERN CALIFORNIA IN RELATION TO THE MONITORING OF WATER QUALITY ABOVE AND BELOW A LAND DISTURBANCE

by

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ABSTRACT

In-stream water quality regulations of California state that silvicultural disturbances must not increase turbidity levels more than 20 percent above naturally occurring background levels. These regulations fail to take into account the natural variation of turbidity and suspended sediment concentration along a short stretch of an undisturbed stream. At Janes Creek and Miller Creek in northwestern California, natural variations in turbidity and suspended sediment concentration along stream reaches of 292.6 and 110.6 meters. were -.015 to 3.73 times that of the 20 percent man-induced increase tolerated by law.

The simple linear regression model $LOG(Y) = B_o + B_1 LOG(X_1)$, where $LOG(Y)$ and $LOG(X_1)$ were logarithms of the suspended sediment concentration or turbidity at the downstream and upstream monitoring stations, respectively, produced r^2 values greater than .92 at Janes Creek and close to .82 at Miller Creek. Predictions of turbidity and suspended sediment concentration from discharge alone were not nearly as accurate as the above model. Expanding the model $LOG(Y) = B_o + B_1 LOG(X_1)$ by adding discharge, variables related to discharge, and month of the hydrologic year did not significantly improve the prediction of the dependent variable. Predictions of suspended sediment concentration based on upstream turbidity were slightly less accurate than predictions made solely from upstream suspended sediment concentration.

Although residual diagnostics showed that the assumptions of linear regression analysis had not been violated, the dissimilar

coefficients of the Janes Creek and Miller Creek regression equations indicated that the equations were stream specific.

ACKNOWLEDGEMENTS

The data upon which this thesis is based was collected from 1979 -1982 by employees of the U.S. Forest Service's Pacific Southwest Forest and Range Experiment Station in Arcata, California. I took no part in the collection of this data.

I would like to thank William Bigg, Robert Thomas, and Carlton Yee for their reviews of this thesis. The guidance of Robert Thomas was instrumental in its completion. I greatly appreciate the use of the computer facilities at the U.S. Forest Service's Pacific Southwest Forest and Range Experiment in Arcata, as well as the assistance offered by several of its employees. Diane Rainsford, in particular, was most helpful in solving my computer problems.

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INTRODUCTION

Purpose

The purpose of this study was to measure and predict the variation of turbidity and suspended sediment concentration along part of the longitudinal profile of two streams contained in forested, undisturbed watersheds of northwestern California. In-stream water quality standards of California, Oregon, and Washington implicitly assume uniform turbidity and suspended sediment concentrations along short, longitudinal stretches of an undisturbed stream. The results of this study were used to evaluate this assumption as it relates to the technique of monitoring the water quality of a stream above and below a silvicultural disturbance.

"Above and Below" Stream Monitoring

California water quality regulations state that activities such as timber harvesting must not increase the turbidity levels of adjacent streams more than 20 percent above naturally occurring background levels (Water Quality Control Board 1972). In practice, "background levels" are defined by turbidity measurements taken on the stream just above the area of tree removal or other activity. These measurements are then compared to turbidity readings taken on the stream just below the watershed disturbance. An increase in turbidity levels below the disturbance is usually interpreted to be the result of the silvicultural activity. The implicit assumption is that the absence of a watershed disturbance would result in identical turbidity readings and levels of suspended sediment at both stream locations (figure 1).

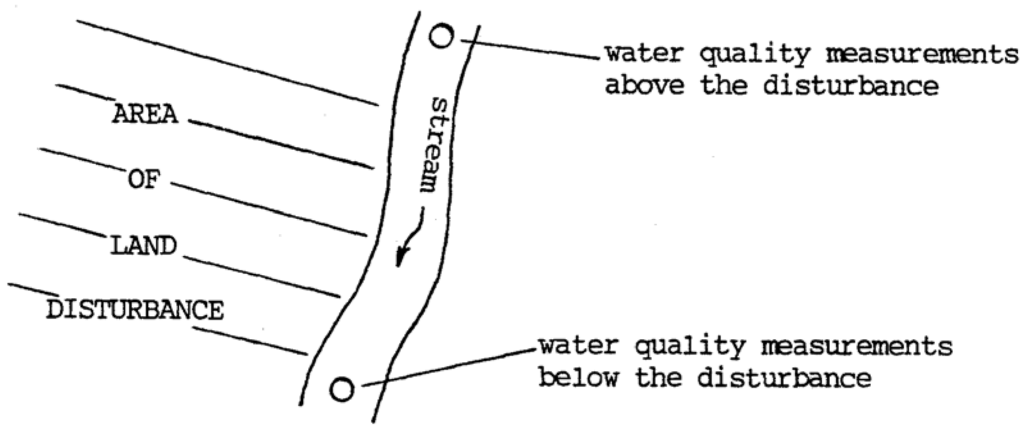

Figure 1. Generalized Diagram of "Above and Below" Stream Monitoring in Relation to an Area of Land Disturbance.

In order to evaluate the "above and below" stream monitoring approach, the U.S. Forest Service's Pacific Southwest Forest and Range Experiment Station in Arcata, California, constructed monitoring stations on Janes Creek and Miller Creek, two streams located in undisturbed, forested watersheds of northwestern Humboldt County. Turbidity and suspended sediment samples were taken from two or three stations simultaneously at 30 or 60 minute time intervals during 12 storm events on Janes Creek and six different storm events on Miller Creek. Except for five storms on Janes Creek, a continuous record of discharge was recorded at the lower monitoring station of each stream.

The two stations on Miller Creek were located 110.6 meters apart; the three stations on Janes Creek spanned a distance of 412.1 meters.

Previous Work

The few intensive turbidity and suspended sediment data sets collected on streams in northwestern California either a.) assess the impacts of erosion and sedimentation on the beneficial uses of streams, or b.) define a stream or basin specific empirical relationship between turbidity and suspended sediment concentration. There are no data sets in northwestern California which measure the longitudinal variation of suspended sediment and turbidity of a stream contained in an undisturbed, forested watershed.

In theory, suspended sediment concentration and turbidity should vary along an undisturbed stream over distances as small as the 110.6 meters between the two monitoring stations at Miller Creek. Hydraulic conditions such as stream velocity and channel characteristics can change enough over short stream stretches so that the power of the stream to entrain and carry sediment will not be the same at two points (Dunne and Leopold 1978).

Turbidity, because of its relative ease of field measurement, is usually sampled instead of suspended sediment concentration when establishing the water quality of a stream. Most hydrologists, however, are interested in suspended sediment, which lends itself to calculating erosion losses and sediment yields. Although often used interchangeably, turbidity and suspended sediment may be very well correlated or completely uncorrelated, depending on the particular stream and the exact location on the stream where the two quantities are being sampled (Kunkle and Comer 1971). Duchrow and Everhart (1971) concluded that "turbidity of water is a questionable parameter for establishing water quality standards, because too many factors must remain constant before a J.T.U. [Jackson Turbidity Unit] can be connected to any corresponding sediment concentration."

THE STUDY AREA

Location

Janes Creek and Miller Creek are located in northwestern Humboldt County, a part of the north coastal region of California. The study area on Janes Creek, contained in the Arcata Community Forest, extends from the power line crossing in section 27, T. 5 N., R. 1 E., Humboldt Base Meridian, upstream for a distance of 412.1 meters (figure 2). The study area on Miller Creek, a tributary of Redwood Creek in Redwood National Park, is located on the border of sections 19 and 30 of T. 10 N., R. 1 E., Humboldt Base Meridian (figure 3).

Climate

Warm, dry summers and cooler, rainy winters are characteristic of the north coastal region of California. Annual rainfall is 114-152 cm./year on the Janes Creek watershed and 152-202 cm./year on the Miller Creek watershed. Approximately 80 percent of the annual precipitation falls in the period of November through April (Dean 1971). Since the elevations of the watersheds are under 610 meters, snow is an infrequent occurrence.

Geology and Soils

The lithology of the Janes Creek watershed consists of Pleistocene nonmarine sedimentary gravel, sand, and clay deposits of the Hookton Formation (Campbell 1962). The Hely soil series, a medium to dark brown soil covering almost the entire watershed, is well-drained

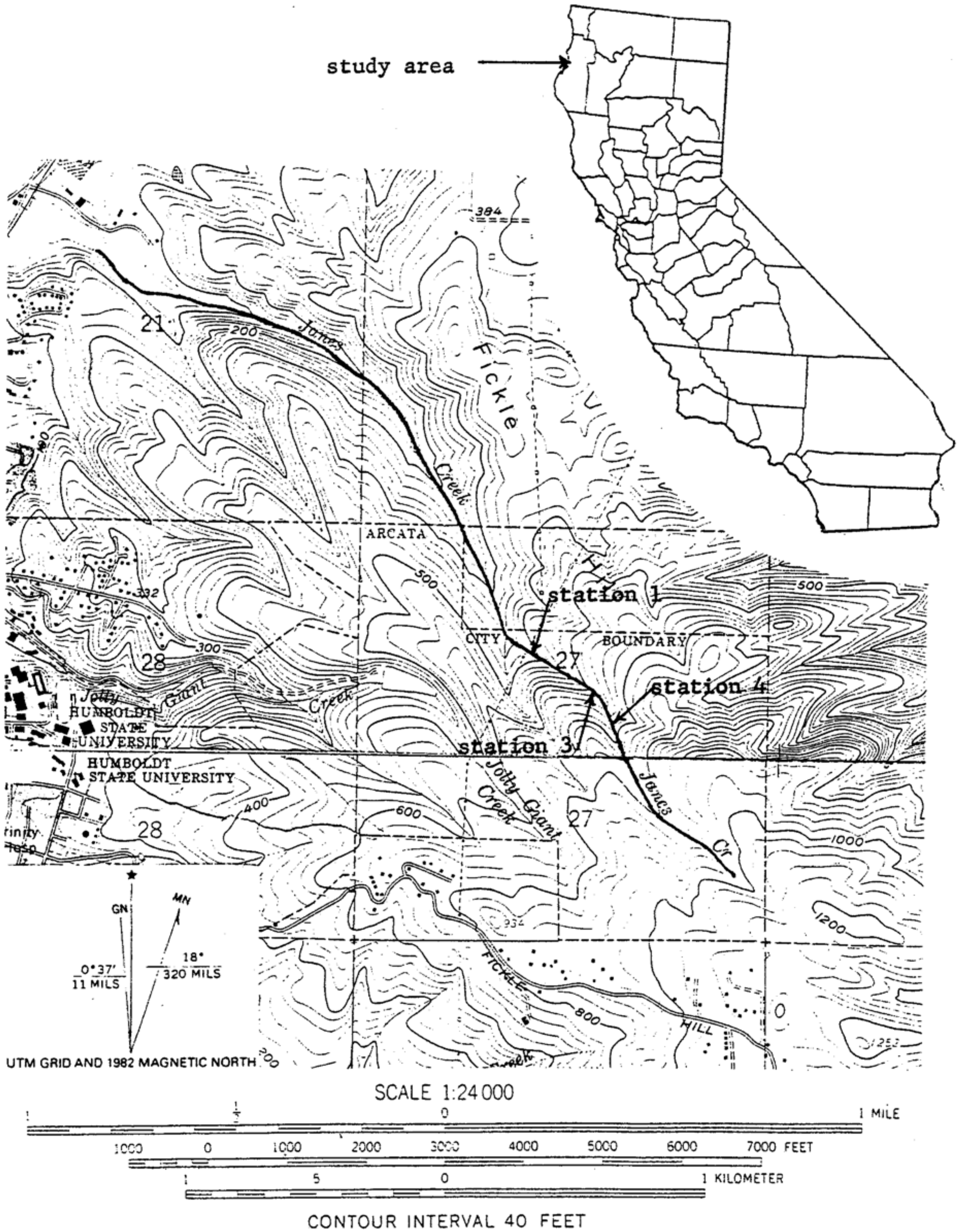

Figure 2. Map of Janes Creek study area showing location of monitoring stations.

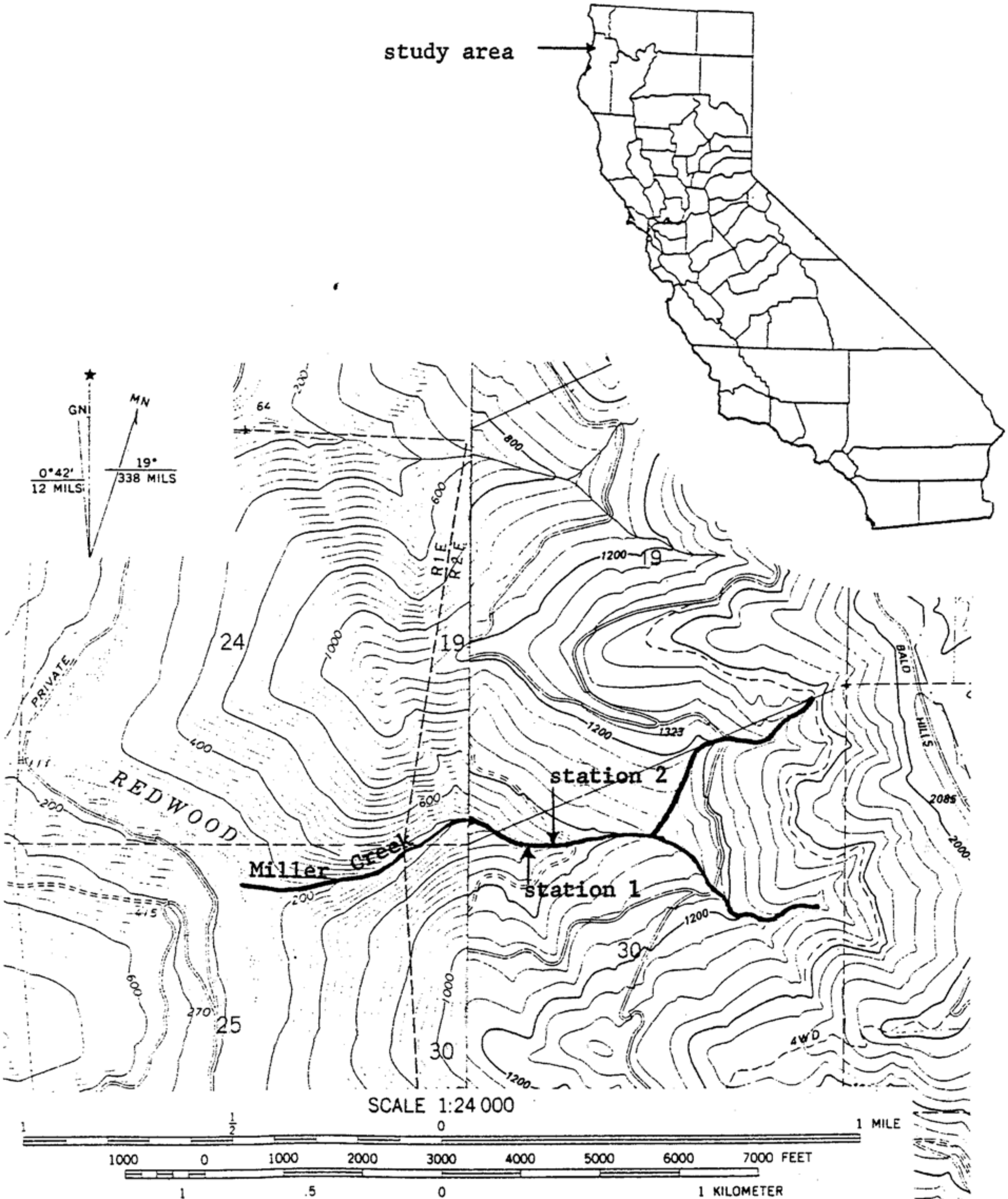

Figure 3. Map of Miller Creek study area showing location of monitoring stations.

with a sandy loam/loam texture extending to a depth of 114-178 centimeters. The erosion hazard of this soil is considered to be high (U.S. Department of Agriculture 1975).

The lithology of the Miller Creek watershed consists of pre-Cretaceous metasedimentary rocks composed mostly of quartzites, mica schist, phyllite, and metachert (Strand 1963). The watershed is covered by the Masterson and Orick soil series, both of which have good drainage characteristics and a moderate to high erosion hazard. The yellowish brown to brown Masterson soil series has a loam/gravelly loam texture with a depth range of 76-152 centimeters. The brown to dark brown Orick soil series has a loam/clay loam texture with a depth exceeding 100 cm. (California Department of Forestry 1961).

Drainage Basin Characteristics

Although the terrain of both watersheds is mountainous with steep slopes, the gradient of Miller Creek is more than twice that of Janes Creek. Basin characteristics are summarized in table 1. Stream profiles are illustrated in figure 4.

Vegetation

Both watersheds are dominated by redwood (*Sequoia sempervirens*), although Sitka spruce (*Picea sitchensis*), grand fir (*Abies grandis*), Douglas-fir (*Pseudotsuga menziesii*), and white fir (*Abies concolor*) occur also (U.S. Department of Agriculture 1975).

The two watersheds, although not completely covered by virgin forest or uniform second growth forest, were considered to be in an essentially undisturbed state during the 1979-1982 monitoring period.

Table 1. Summary of Basin Characteristics for Janes Creek and Miller Creek.

	Janes Creek	Miller Creek
Maximum basin elevation, meters	381	636
Minimum basin elevation, meters	43	31
Total basin relief, meters	338	605
Stream Channel relief, meters	256	451
Stream channel length above monitoring station #1, meters	1,250	1,380
Mean gradient of entire stream channel, in percent	6.7	16.9
Mean gradient of stream at location of monitoring stations, in percent	13	17
Area of watershed above lowest monitoring station, hectares	61	232
Drainage pattern	linear	dendritic
Drainage orientation	northwest	east-west

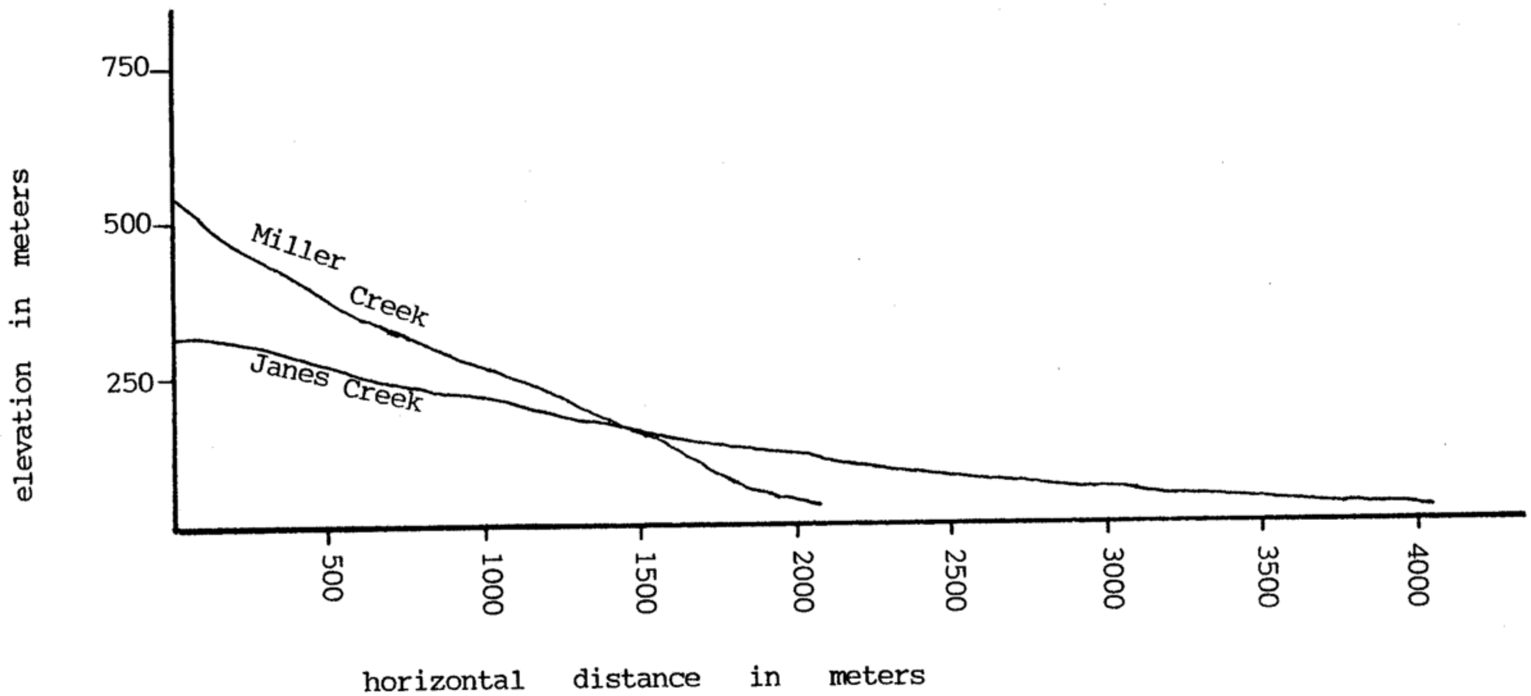

Figure 4. Longitudinal Profile of Janes Creek and Miller Creek.

The Janes Creek watershed, except for a small, selective cut 18 years ago, has not been logged for about 60 years. Small, selective cuts were made in the upper reaches of the Miller Creek watershed from 1968 through 1977; the rest of the watershed has never been logged.

METHODS

Location of Monitoring Stations

In order to minimize differences in suspended concentration between stations resulting solely from pool/riffle sequence variations, each monitoring station on Janes Creek and Miller Creek was located in the transition zone below a stream pool and above the adjacent lower riffle.

The spacing between stations was chosen to simulate the stream lengths that might border square blocks of logged timber. The distances between the three Janes Creek monitoring stations roughly approximated the lengths of squares of 1.4, 8.6, and 17.0 hectares (figure 5). The spacing between the two Miller Creek stations approximated the length of a 1.2 hectare cutblock (figure 6).

Instrumentation

During the storm events on Janes Creek dating from January 1979 through May 1979, a nominal .474 liter, depth and width integrated suspended sediment sample was taken at two or three stations simultaneously at 30 minute intervals using hand-held DH-75 suspended sediment samplers. A staff gauge, located in a semi-permanent spot at station one, was used to read stream height at times corresponding to sediment sampling.

After May 1979, the suspended sediment samples on Janes Creek and all samples on Miller Creek were taken at two or three stations simultaneously using small, automatic pumping samplers connected to a

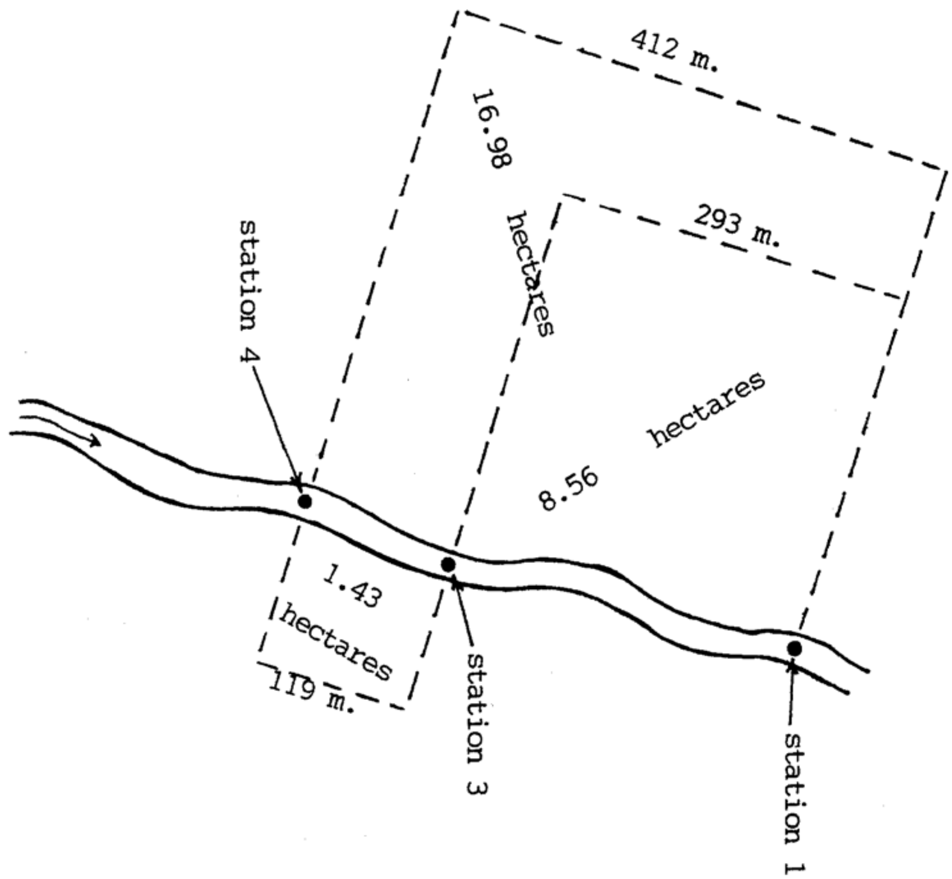

Figure 5. Spacing between monitoring stations on Janes Creek.

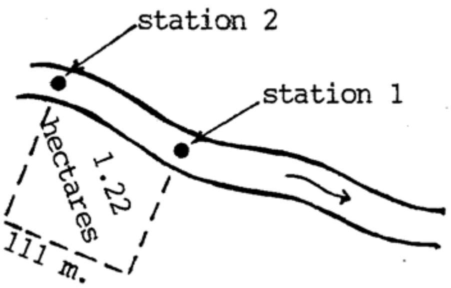

Figure 6. Spacing between monitoring stations on Miller Creek.

1.52 meter long, depth-proportional intake "boom" (figure 7). Installation of this device was such that samples from each monitoring station, regardless of stage, would be taken at approximately the same relative depth in the stream channel cross-section. Details concerning the installation and use of the depth-proportional intake boom were described by Eads and Thomas (1983). After May of 1979, stream stage was recorded with a continuous stage recorder at stations one of Janes Creek and Miller Creek. Instantaneous discharges were later calculated from the discharge-rating curve relationship previously developed for station one of each stream.

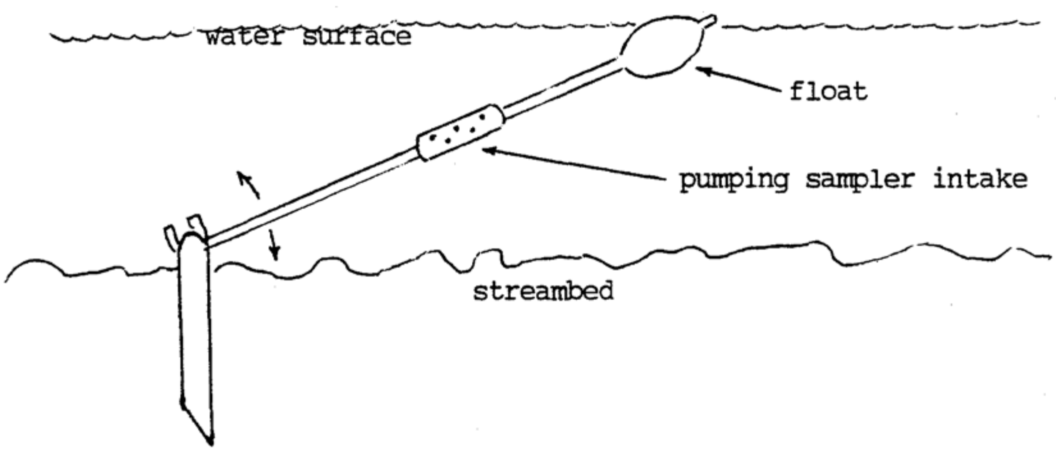

Figure 7. Simplified Diagram of the Depth-Proportional Intake "Boom" Used to Take Suspended Sediment Samples at Janes Creek and Miller Creek.

All suspended sediment samples were analyzed at the U.S. Forest Service Pacific Southwest Forest and Range Experiment Station, 1700 Bayview Drive, Arcata, California. Suspended sediment concentration was measured in milligrams per liter (mg./l.) and turbidity in Jackson Turbidity Units (J.T.U.). Details concerning field and laboratory procedures can be obtained from Robert Thomas, Mathematical Statistician, or Rand Eads, Hydrologic Technician, at the above address.

Description of the Data Set

Suspended sediment samples from Janes Creek yielded 452-495 observations of suspended sediment concentration and turbidity per monitoring station. The sampling period from January 1979 through April 1980 included 12 storm events; the time interval between sampling was 30 minutes for all but two storms. Instantaneous discharge measurements corresponding to the timing of suspended sediment sampling were available for only seven storms.

Suspended sediment samples from Miller Creek, taken 30 minutes apart at two monitoring stations simultaneously, yielded approximately 394 measurements of suspended sediment concentration and turbidity per station. Data were collected during six storm events from December 1980 through March 1982. Instantaneous discharge measurements corresponding to the timing of suspended sediment sampling were available for each storm. Table 2 summarizes the data collected for each storm for Janes Creek and Miller Creek.

Table 2. Summary of information pertaining to data collected at Janes Creek and Miller Creek by the U.S. Forest Service Pacific Forest and Range Experiment Station in Arcata, California.

*Storm #	Stations with susp. sed. and turb. data	# of susp. sed. and turbitity measure-ments per station	time interval between observa-tions in minutes	Discharge data for station 1?	dates of storm
1	1;3;4	50	30	yes	1-10 to 1-11, '79
2	1;3	35	30	yes	2-12 to 2-13, '79
3	1;3	17	30	yes	5-5 to 5-5 , '79
5	1;3	62	30	yes	5-7 to 5-8 , '79
6	1;3	24	30	no	12-21 to 12-21,'79
7	1;3;4	26	30	no	12-30 to 12-31,'79
8	1;3;4	41	30	no	1-9 to 1-10, '79
9	1;3;4	93	60	no	1-11 to 1-15, '80
10	3;4	95	30	no	2-18 to 2-20, '80
11	1;3;4	26	30	yes	2-27 to 2-27, '80
12	1;3;4	96	30	yes	3-13 to 3-15, '80
13	1;3;4	25	60	yes	4-20 to 4-21, '80
14	1;2	48	30	yes	12-2 to 12-3, '80
15'	1;2	63	30	yes	1-22 to 1-23, '81
16	1;2	65	30	yes	2-13 to 2-14, '81
17	1;2	99	30	yes	11-15 to 11-17,'81
18	1;2	82	30	yes	2-14 to 2-16, '82
19	1;2	37	30	yes	2-28 to 3-1 , '82

*Storms 1-13 : Janes Creek
Storms 14-19: Miller Creek

Data Analysis

In order to simplify the analyses, measurements of suspended sediment concentration and turbidity at station four of Janes Creek were not used. This reduced data analysis to differences in suspended sediment concentration/turbidity between two stations on Janes Creek and two stations on Miller Creek.

Evaluation of the Differences between Monitoring Stations

Relative differences between simultaneously collected suspended sediment concentrations were calculated at stations one and three of Janes Creek for storms 1-13 and at stations one and two of Miller Creek using storms 14-19. The relative difference in suspended sediment concentration between two stations was defined as:

$$(Y_1 - Y_2) / Y_2 ,$$

where Y_1 = the suspended sediment concentration at the downstream station at time t,

and Y_2 = the suspended sediment concentration at the upstream station at time t.

Various statistics were computed from these relative differences in order to characterize the variation of turbidity and suspended sediment concentration of the monitored stream sections.

Relative differences and associated statistics were also calculated for turbidity readings. For both suspended sediment concentrations and turbidity measurements, relative differences between stations of less than five percent were judged to be insignificant and within the limits of equipment and sampling error (Thomas, personal communication).

Time-series Modeling

Sampling water-quality characteristics at two points in a stream at the same time and at constant time intervals suggested that time-series techniques might have been appropriate for developing a predictive model. The first step of time-series analysis involved removal of the trend in the data through the technique of differencing, described by Chatfield (1984). Correlograms were formed from the differenced values of suspended sediment concentration of station one for several storms from Miller Creek and Janes Creek. Both the autocorrelation function (A.C.F.) and the partial autocorrelation function (P.A.C.F.) of suspended sediment concentration for all storms indicated a lack of correlation in the data. This suggested that the data was "white noise," and not suitable for fitting a time-series model (Chatfield 1984).

Linear Regression Modeling

The procedure used in linear regression analysis followed seven steps.

1.) Two subsamples, one from the Janes Creek data set (storms 1-13) and one from the Miller Creek data set (storms 14-19), were formed in order to develop a stream-specific linear regression model that would predict suspended sediment concentration and turbidity at a lower station from that measured at an upstream station. Every fourth observation was extracted from storms 1-5 and 11-13 (the storms on Janes Creek with discharge measurements) to form one data set for Janes Creek. The same procedure was done to all the storms from Miller Creek. The purpose of selecting every fourth data point was to a.)

reduce possible serial correlation between adjacent observations, b.) allow cross-validation of the selected linear regression model(s), and c.) produce a data set more representative of the size that might actually be taken by field hydrologists. The sample data sets of 75 and 96 observations for Janes Creek and Miller Creek, respectively, are reproduced in Appendix A. From this point onward, the abbreviations in table 3 will replace the longer, more descriptive names.

2.) The appropriateness of a linear model was determined. The basic field data, SUSP1, SUSP2, and FLOW for Miller Creek was plotted as bivariate graphs (figures 8 and 9). The graph of SUSP1 vs. FLOW (figure 8) did not show a strong linear relationship between the two untransformed variables, although SUSP1 tended to increase with increasing FLOW. The graph of SUSP1 vs. SUSP2 (figure 9) indicated a linear relationship to a degree, but the "spread" of the data points was not uniform. Most of the data points were clustered at low suspended sediment concentrations, an indication that linear regression analysis of the untransformed data was not appropriate (Kleinbaum, et. al. 1988). Graphs of SUSP1 vs. FLOW and SUSP1 vs. SUSP3 from Janes Creek demonstrated similar patterns and also lead to the conclusion that linear regression of the untransformed data was inappropriate.

A logarithmic transformation was performed on each variable, and the results plotted in figures 10 and 11. The graph of L_SUSP1 (logarithm to the base 10 of SUSP1) vs. L_SUSP2 (logarithm to the base 10 of SUSP2), in particular, appeared to violate none of the necessary assumptions of linear regression analysis. The data points were spread fairly evenly over a wide range of values and a strong, linear, upward trend was apparent. The assumptions of homoscedasticity {homogeneity

Table 3: Abbreviations for Water Quality and Stream Flow Parameters for Janes Creek and Miller Creek Data Sets.

SUSP1 : suspended sediment concentration at station 1, the downhill or "lower" station (Janes and Miller Creeks).
SUSP2 : suspended sediment concentration at station 2, the upstream or "upper" station (Miller Creek).
SUSP3 : suspended sediment concentration at station 3, the upstream or "upper" station (Janes Creek).
TURB2 : turbidity at station 1, the downhill or "lower" station (Janes and Miller Creeks).
TURB2 : turbidity at station 2, the upstream or "upper" station (Miller Creek).
TURB3 : turbidity at station 3, the upstream or "upper" station (Janes Creek).

FLOW : instantaneous discharge ($m.^3/s.$) at station 1.
CFLOW : cumulative discharge ($m.^3/s.$) during a specific storm.
MFLOW : maximum discharge ($m.^3/s.$) for a specific storm.
MONTH : month of the hydrologic year of a specific storm's occurence (August=1, September=2, etc.).

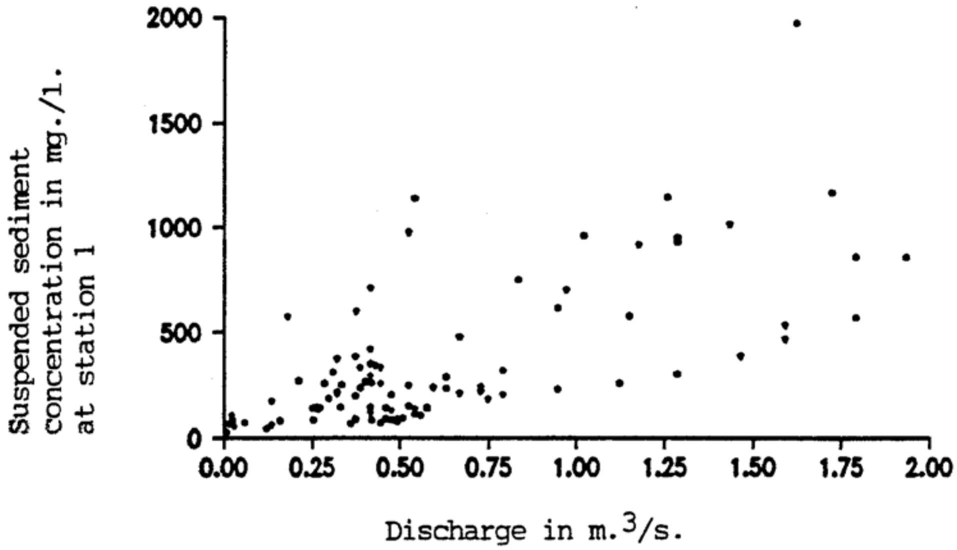

Figure 8. Bivariate Plot of the Suspended Sediment Concentration at Station 1 and the Discharge at Station 1 for Miller Creek.

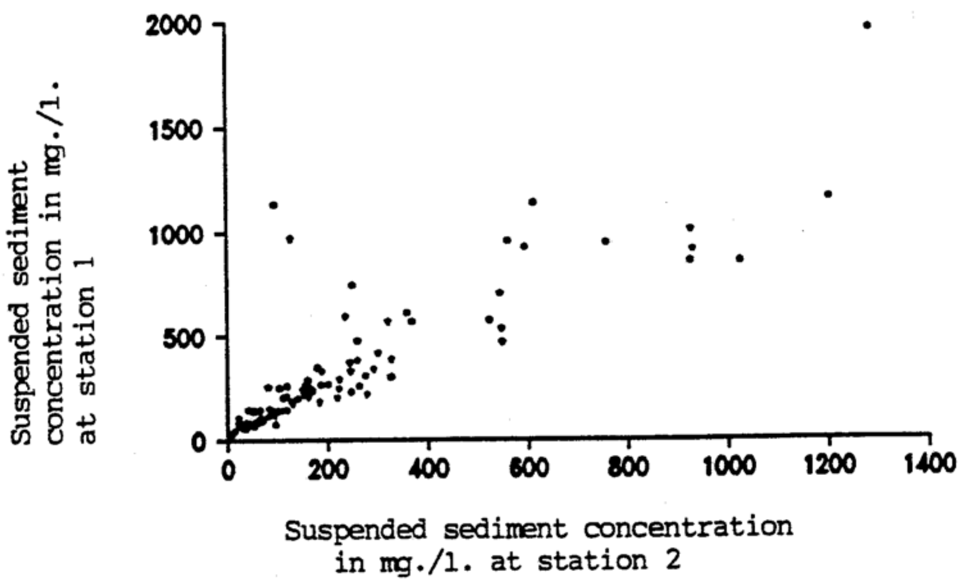

Figure 9. Bivariate Plot of the Suspended Sediment Concentration at Stations 1 and 2 for Miller Creek.

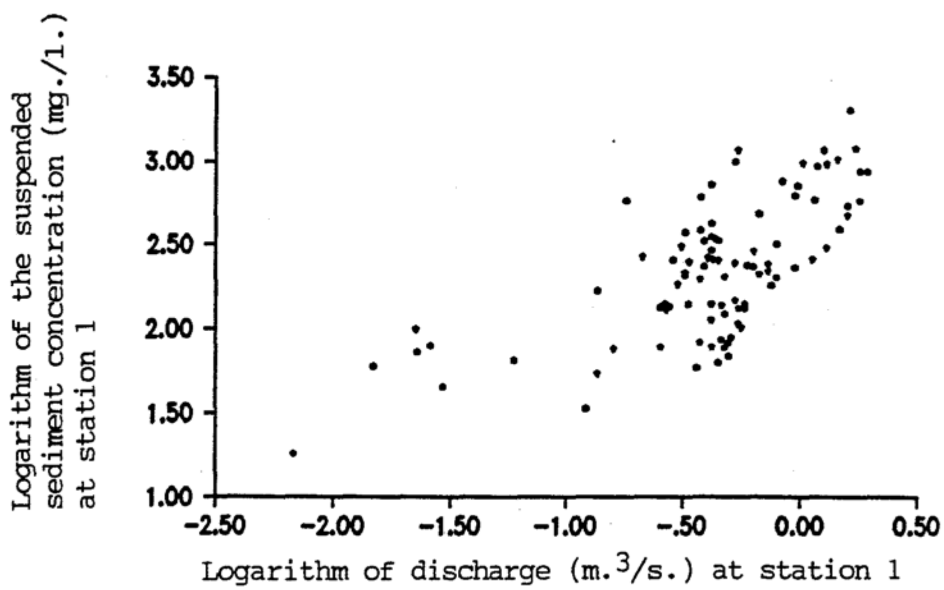

Figure 10. Bivariate Plot of the Logarithm of the Suspended Sediment Concentration at Station 1 and the Logarithm of Discharge at Station 1 for Miller Creek.

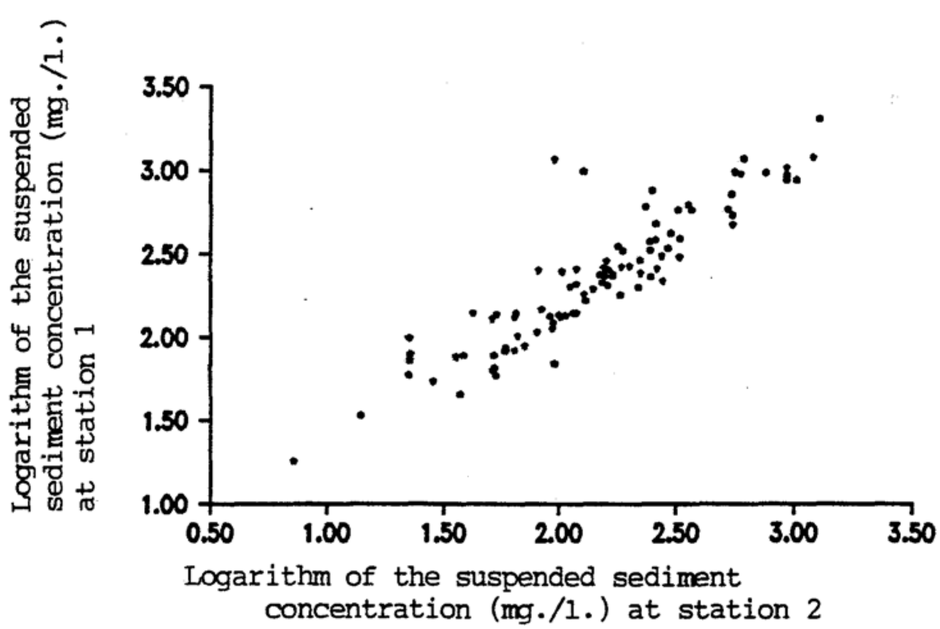

Figure 11. Bivariate Plot of the Logarithm of the Suspended Sediment Concentration at Stations 1 and 2 for Miller Creek.

of variance) and linearity appeared to be satisfied. The graphs of SUSP1 vs. FLOW and L_SUSP1 vs. L_FLOW (logarithm to the base 10 of FLOW) showed a compacted grouping of most of the data points that probably could not have been further linearized by any transformation (Kleinbaum, et al. 1988). Bivariate plots of the logarithmically transformed variables from Janes Creek mirrored those from Miller Creek; the linearity of the data points in the graphs L_SUSP1 vs. L_SUSP3 was more pronounced and the plot of L_SUSP1 vs. L_FLOW showed slightly less clustering of the data points.

The procedure for suspended sediment concentration, outlined in the previous two paragraphs, was repeated for turbidity measurements for Janes Creek and Miller Creek. Graphs of the untransformed and the logarithmically transformed data showed similar patterns as those for suspended sediment; therefore, the conclusions were the same.

3.) Linear model(s) were selected and regression equations were formed. An all possible subsets linear regression was performed by the computer program WINNOW in order to choose the model(s) which best predicted L_SUSP1 and L_TURB1 for Janes Creek and Miller Creek. The independent variables used to predict L_SUSP1 were:

L_SUSP2 or L_SUSP3 : logarithm to the base 10 of SUSP2 (Miller Creek) or SUSP3 (Janes Creek).
L_FLOW : logarithm to the base 10 of FLOW.
L_CFLOW : logarithm to the base 10 of CFLOW.
L_MFLOW : logarithm to the base 10 of MFLOW.
MONTH : month of the hydrologic year.

The independent variables used to predict L_TURB1 were:

L_TURB2 or L_TURB3 : logarithm to the base 10 of TURB2 (Miller Creek) or L_TURB3 (Janes Creek).

L_FLOW : logarithm to the base 10 of FLOW.
L_CFLOW : logarithm to the base 10 of CFLOW.
L_MFLOW : logarithm to the base 10 of MFLOW.
MONTH : month of the hydrologic year.

The criterion used to evaluate the possible regression equations for L_SUSP1 and L_TURB1 for both Janes Creek and Miller Creek was "Mallows' Cp." This statistic, which measures the sum of the squared biases plus the random squared error in Y at all N data points, is thought by many statisticians to be the most powerful single statistic useful in selecting the "best" of the possible linear models (Kleinbaum, et al. 1988). The "best" model is loosely defined as that which strikes a good balance between predictive capability and parsimony.

For each independent variable (L_SUSP1, Miller Creek; L_TURB1, Miller Creek; L_SUSP1, Janes Creek; L_TURB1, Janes Creek), the Cp values of the 31 possible linear regression models were plotted against the line Cp=p. The resulting four graphs, one for each independent variable, showed that models with the smallest bias fell near the line Cp=p, while models with lowest total error (bias + random error) were located closest to the horizontal axis (Daniel 1971). For each of the four independent variables, the model with the lowest total error was then used to formulate an ordinary least squares linear regression equation. Predicted values were calculated for L_SUSP1 and L_TURB1 for Janes Creek and Miller Creek using these equations.

4.) The chosen model(s) were evaluated in terms of their conformity to the assumptions of least squares linear regression analysis. Standardized residual plots and normal probability plots, explained in table 4, were made for each of the four chosen model(s).

Table 4. Summary of the Characteristics of the Standarized Residual Plot and the Normal Probability Plot.

	Y axis	X axis	Assumptions of linear regression for which plot is used to test	Desirable characteristics of the plot
Standardized Residual Plot	standardized residuals (difference between the predicted values of the dependent variable (Y) and the actual Y values, standardized to a z distribution	predicted values of the dependent variable (Y)	linearity; homoscedasticity; outliers	horizontal band of points with no hint of any systematic trend; mean near zero
Normal Probability Plot	cumulative relative frequencies of the standardized residuals	standardized residuals	normality of error terms; outliers	points should plot close to a straight line

The assumptions of linearity and homoscedasticity are satisfied when the standardized residual plot is a horizontal band of points with constant width; the assumption of normality is met when the normal probability plot approximates a straight line (Kleinbaum, et al. 1988). Points located well away from the majority, termed outliers, were not discarded unless they could clearly be traced to an equipment or laboratory error.

A Durbin-Watson statistic was calculated for each ordinary least squares linear regression equation. If first order autocorrelation was indicated, a new regression equation was developed using AUTOREG, a linear regression procedure that does not assume independence of error terms across time (SAS 1985).

5.) The chosen model(s) were tested in terms of reliability, that is, the ability of those models to predict well for subsequent samples. Having already developed a regression equation for L_SUSP1 for Miller Creek based on one subsample data set from that creek, a new subsample was taken. As in the initial sample, the new or "validation" subsample was spaced four observations apart. A coefficient of determination (r^2_1) was calculated between the actual and the predicted values of L_SUSP1 for the initial subsample. A coefficient of determination (r^2_{*2}) was calculated between the actual L_SUSP1 values of the validation subsample and the values of L_SUSP1 (validation subsample) that would be predicted using the regression equation developed from the initial subsample. The difference between r^2_1 and r^2_{*2} was called the "shrinkage on cross-validation" (Kleinbaum, et al. 1988).

The procedure outlined above was repeated for L_TURB1 for Miller Creek and for L_SUSP1 and L_TURB1 for Janes Creek.

6.) For each linear regression equation developed from the chosen model, a tolerance interval was calculated using equation 30 from Miller (1981). The tolerance intervals, taken at a fixed value of the independent variable, were constructed so as to include 90 percent of a large number of future: observations with a .90 probability. Prediction intervals, which bracket a specified number of future observations and would have been too large to be of practical use, were not calculated.

7.) The logarithmic estimates were converted back to arithmetic units. Estimates of L_SUSP1 and L_TURB1 from both creeks were transformed back to the arithmetic units of SUSP1 (suspended sediment concentration in mg./l.) and TURB1 (turbidity in J.T.U.) using an adaptation of the following equation from Baskerville (1971).

if: $\hat{u} = \widehat{LN(Y)} = \hat{B}_0 + \hat{B}_1 LN(X)$

then: $\hat{Y} = e^{u+(\hat{\sigma}^2/2)}$

where: $\hat{Y}$ is the predicted dependent variable in arithmetic units.

$\hat{\sigma}^2$ is the estimated variance.

A straight calculation of the antilogarithm of L_SUSP1 or L_TURB1 would have failed to account for the skewness of the distribution of the arithmetic equivalents SUSP1 and TURB1. This would have yielded the median rather than the mean value of Y (SUSP1 or TURB1) for a given value of X (SUSP2 or TURB2), resulting in a systematic underestimation of the dependent variable (Baskerville 1972).

RESULTS

Differences Between Monitoring Stations

The mean relative difference in suspended sediment concentration between the two monitoring stations on Janes Creek was -.3 percent and 74.6 percent between the two stations on Miller Creek. The mean between-station relative difference in turbidity was -1.6 percent at Janes Creek and 27.9 percent at Miller Creek. Average relative differences greater than 50 percent occurred six to ten times more often at Miller Creek than at Janes Creek; there was no preference for those differences to occur at high discharges. Relative differences less than five percent, judged to be insignificant, occurred far more often at Janes Creek than at Miller Creek and more frequently for turbidity than suspended sediment concentration. Statistics concerning between-station relative differences were calculated from the subsamples used in forming the regression equations. Relative differences for individual storms varied considerably from the across storm averages presented in table 5.

Linear Regression Model Selection

Mallows' graphical method of comparing fitted equations, repeated for each of the four independent variables according to the procedure described by Daniel (1971), showed in each case that the general model $LOG(Y) = \hat{B}_o + \hat{B}_1 LOG(X_1)$ was "best". The model was defined here as:

LOG(Y) : logarithm to the base 10 of SUSP1 or TURB1.

Table 5. Summary of Statistics Relating to the Relative Differences of Suspended Sediment Concentration / Turbidity between Stations on Janes Creek and the Relative Differences between Stations on Miller Creek. Statistics were-calculated using subsamples from the Janes Creek and Miller Creek data sets. Janes Creek: n=75. Miller Creek: n=96.

	Janes Creek		Miller Creek	
	suspended sediment	turbidity	suspended sediment	turbidity
relative difference between stations, %				
mean	-.3	-1.6	74.6	27.9
median	-6.1	-2.4	38.3	15.8
standard dev.	32.9	11.2	13.8	57.0
minimum	-62.5	-61.5	-30.2	-86.7
maximum	193.5	23.5	1082.3	437.5
percent of observations for which difference between stations ≤ 5%	15.1	60.3	7.5	17.2
percent of time in which relative difference between stations ≥ 50%				
all discharges	6.8	1.3	41.9	14.0
low discharges*	6.1	2.0	43.3	19.4
high discharges**	8.3	0.0	34.6	11.5

*less than .09m.^{3}/s. for Janes Creek; less than .65m.^{3}/s. for Miller Creek.

**greater than or equal to .09m.^{3}/s. for Janes Creek; greater than or equal to .65m.^{3}/s. for Miller Creek.

$LOG(X_1)$: logarithm to the base 10 of SUSP2 [SUSP3] or TURB1 [TURB3].

$\hat{B}_o$: value of the intercept of the regression line with the LOG(Y) axis.

$\hat{B}_1$: value of the slope of the regression line.

The model using L_FLOW as the only independent variable, which corresponds to the sediment rating curve commonly used by hydrologists, resulted in r^2 values that were 26 to 44 percent less than r^2 values from the model $LOG(Y) = \hat{B}_o + \hat{B}_1 LOG(X_1)$. The model incorporating all five independent variables did little to increase r^2 values above those from the simple model $LOG(Y) = \hat{B}_o + \hat{B}_1 LOG(X_1)$. Comparison of values of r_1^2 between the three predictive models, summarized in table 6, showed this statistic to be 17 to 44 percent less at Miller Creek than at Janes Creek.

Linear Regression Equations and Predictions

The coefficients $\hat{B}_o$ and $\hat{B}_1$ of the least squares linear regression equations, which were produced from the general model $LOG(Y) = \hat{B}_o + \hat{B}_1 LOG(X_1)$, were different for each creek. For both Janes and Miller Creeks, the correlation between L_SUSP1 and L_SUSP2 (or L_SUSP3) was slightly higher than the correlation between L_SUSP1 and L_TURB2 (or L_TURB3). In general, values of SUSP1 were more accurately predicted by SUSP2 (or SUSP3) than by TURB2 (or TURB3).

Values of r^2 for Miller Creek were 15 to 18 percent less than those for Janes Creek. This was due to larger residual sums of squares for the Miller Creek regression equations, which in turn explained the higher standard deviations for Miller Creek. At a level of significance of .999, computed F statistics showed the independent variable (L_SUSP2 or L_SUSP3; L_TURB2 or L_TURB3) to significantly

Table 6. Comparison of R^2 (or r^2) values between three predictive models for each dependent variable from Janes Creek and Miller Creek.

	model	R^2 (or r^2)
JANES CREEK	L_SUSP1= B_o + B_1 L_SUSP3	.9371
	L_SUSP1= B_o + B_2 _FLOW	.6900
	L_SUSP1= B_o + B_1 L_SUSP3 + B_2 L_FLOW + B_3 L_CFLOW + B_4 L_MFLOW + B_5 MONTH	.9431
	L_TURB1= B_o + B_1 L_TURB3	.9746
	L_TURB1= B_o + B_2 L_FLOW	.7027
	L_TURB1= B_o + B_1 L_TURB3 + B_2 L_FLOW + B_3 L_CFLOW + B_4 L_MFLOW + B_5 MONTH	.9774
MILLER CREEK	L_SUSP1= B_o + B_1 L_SUSP2	.8143
	L_SUSP1= B_o + B_2 L_FLOW	.4610
	L_SUSP1= B_o + B_1 L_SUSP2 + B_2 L_FLOW + B_3 L_CFLOW + B_4 L_MFLOW + B_5 MONTH	.8261
	L_TURB1= B_o + B_1 L_TURB2	.8112
	L_TURB1= B_o + B_1 L_FLOW	.4973
	L_TURB1= B_o + B_1 L_TURB2 + B_2 L_FLOW + B_3 L_CFLOW + B_4 L_MFLOW + B_5 MONTH	.8185

contribute to the prediction of the dependent variable (L_SUSP1 or L_TURB1). Regression equations and corresponding statistics are shown in table 7. Graphs of the relationships, including tolerance intervals, are illustrated in figures 12-17. Observed and predicted values of the dependent variables are listed in Appendixes B and C.

Linear Regression Model Evaluation

Residual Plots

The standardized residual plot for suspended sediment concentration at station 1 (SUSP1) of Miller Creek showed a horizontal band of points lacking any apparent systematic trend (figure 18). This indicated homoscedasticity and linearity, which in turn implied that the correct model had been chosen to fit the data (Kleinbaum, et al. 1988).

The normal probability plot for the standardized residuals of the suspended sediment concentration at station 1 of Miller Creek approximated a straight line with S-shaped ends (figure 19). This shape indicated a rough normality of error terms with the presence of several large outliers (Kleinbaum, et al. 1988.) These outliers, enclosed in circles in figures 18 and 19, were not discarded as they could not be traced to an equipment or laboratory error.

The standardized residual and normal probability plots of the three other dependent variables (L_TURB1, Miller Creek; L_SUSP1, Janes Creek; L_TURB1, Janes Creek) were almost identical to the standardized residual plot and normal probability plot of L_SUSP1, Miller Creek. This supported the conclusion that the model chosen to predict L_SUSP1

Table 7. Least Squares Linear Regression Equations Used to Predict the Logarithm of the Suspended Sediment Concentration at Station One (L_SUSP1) and the Logarithm of Turbidity at Station One (L_TURB1) for Janes Creek and Miller Creek. The Equation with an Asterisk was Calculated Using the Method of Ordinary Least Squares. All other Equations were Calculated Using AUTOREG, a Linear Regression Procedure which does not Assume Independence of Error Terms Across Time.

Creek	Equation	n[a]	r^2[b]	$S_{y/x}$[c]	F[d]
Janes	L_SUSP1 = -.0026 + .990L_SUSP3	107	.957	.1077	2305
	*L_TURB1 = .0246 + .983L_TURB3	109	.975	.0559	4468
	L_SUSP1 = -.494 + 1.430L_TURB3	108	.949	.1176	1979
Miller	L_SUSP1 = .600 + .807L_SUSP2	93	.812	.1750	394
	L_TURB1 = .503 + .769L_TURB2	93	.809	.1372	389
	L_SUSP1 = .534 + .982L_TURB2	96	.780	.1894	336

a) n = Sample Size.
b) r = Coefficient of Determination, adjusted for sample size.
c) $S_{y/x}$ = Standard Deviation of Y about the regression line.
d) F = F Statistic, calculated from the sample data.

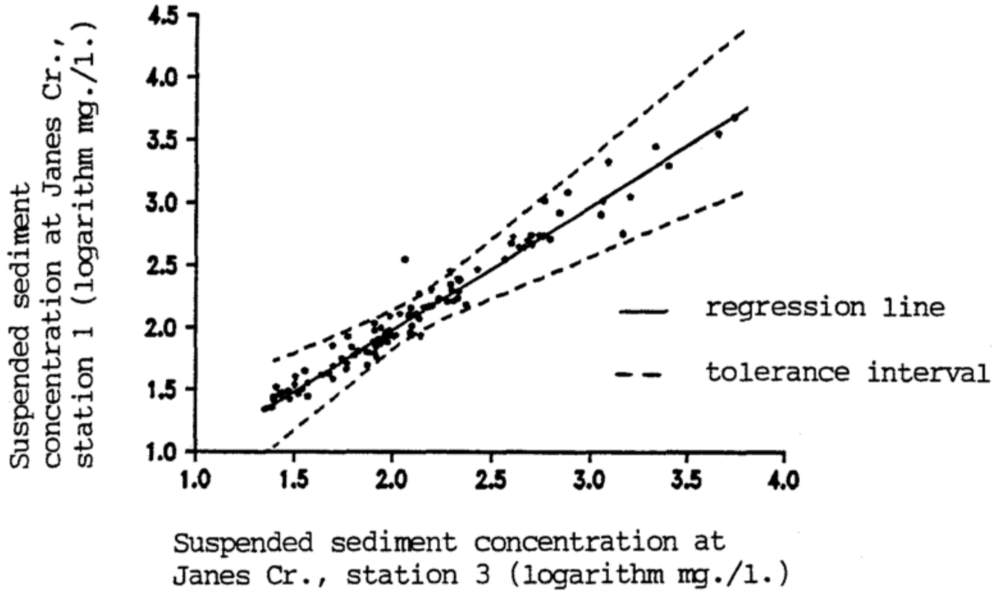

Figure 12. Suspended sediment concentrations at Janes Cr., station 1, regressed on simultaneous measurements at station 3. Tolerance bands cover at least 90% of normal distributions with 90% probability.

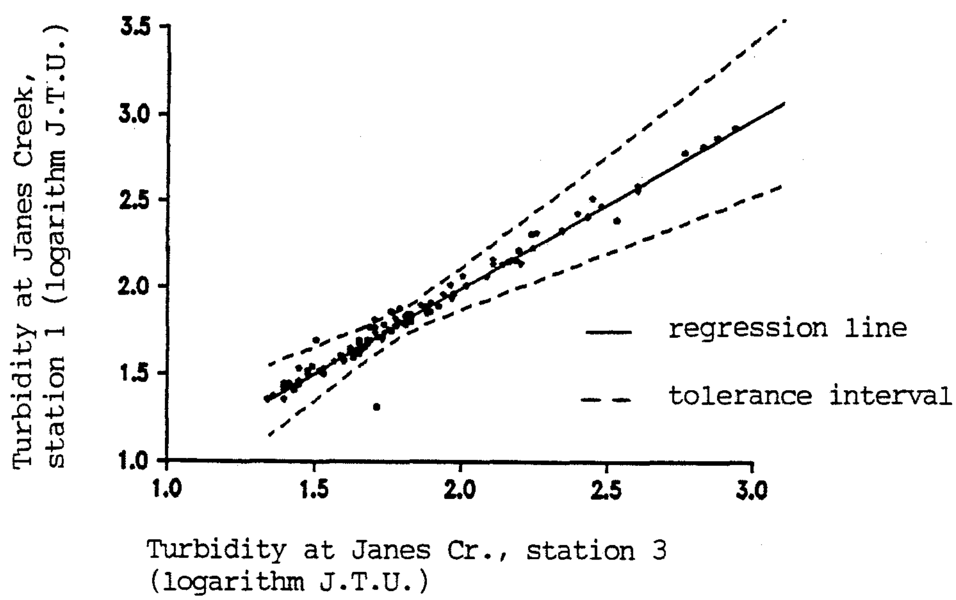

Figure 13. Turbidity at Janes Creek, station 1, regressed on simultaneous measurements at station 3. Tolerance bands cover at least 90% of normal distributions with 90% probability.

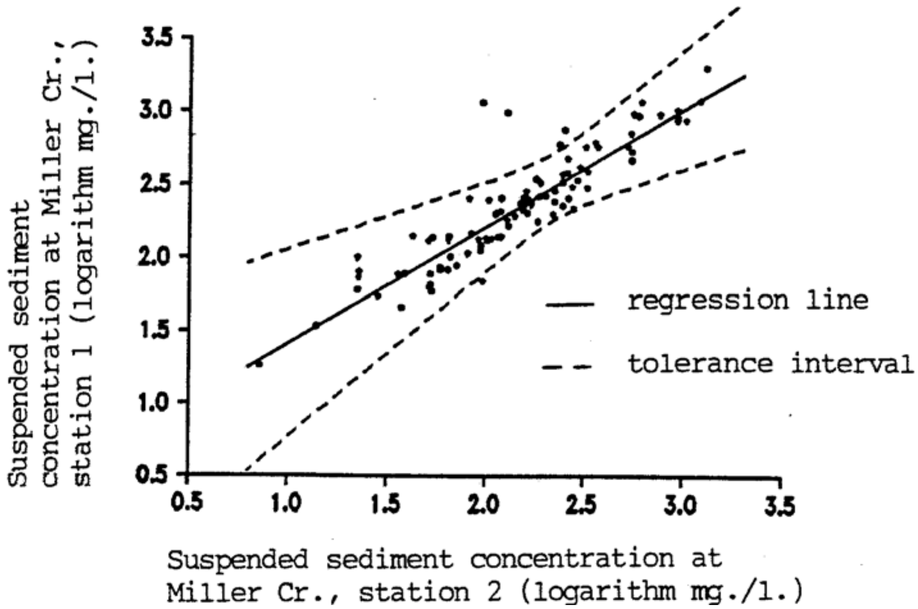

Figure 14. Suspended sediment concentrations at Miller Cr., station 1, regressed on simultaneous measurements at station 2. Tolerance bands cover at least 90% of normal distributions with 90% probability.

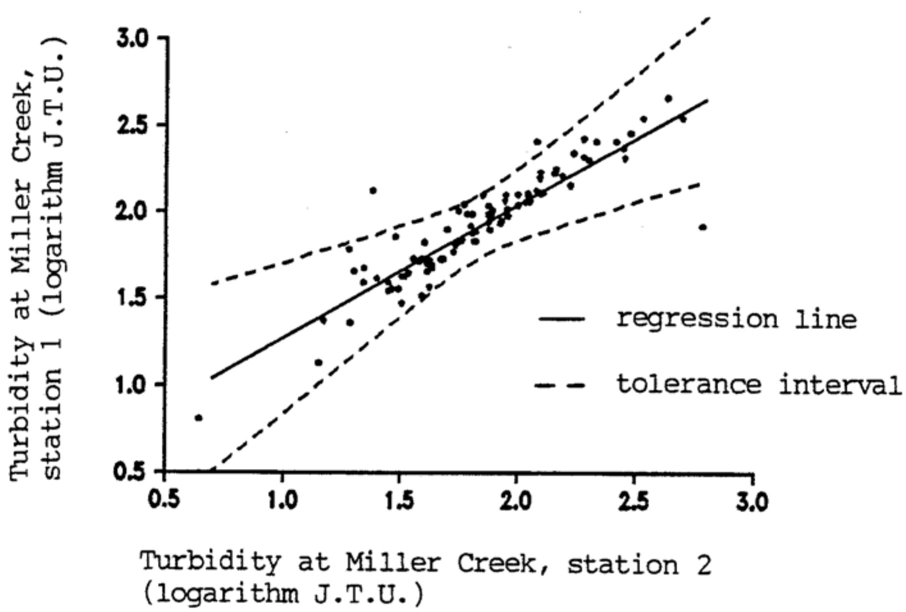

Figure 15. Turbidity at Miller Creek, station 1, regressed on simultaneous measurements at station 2. Tolerance bands cover at least 90% of normal distributions with 90% probability.

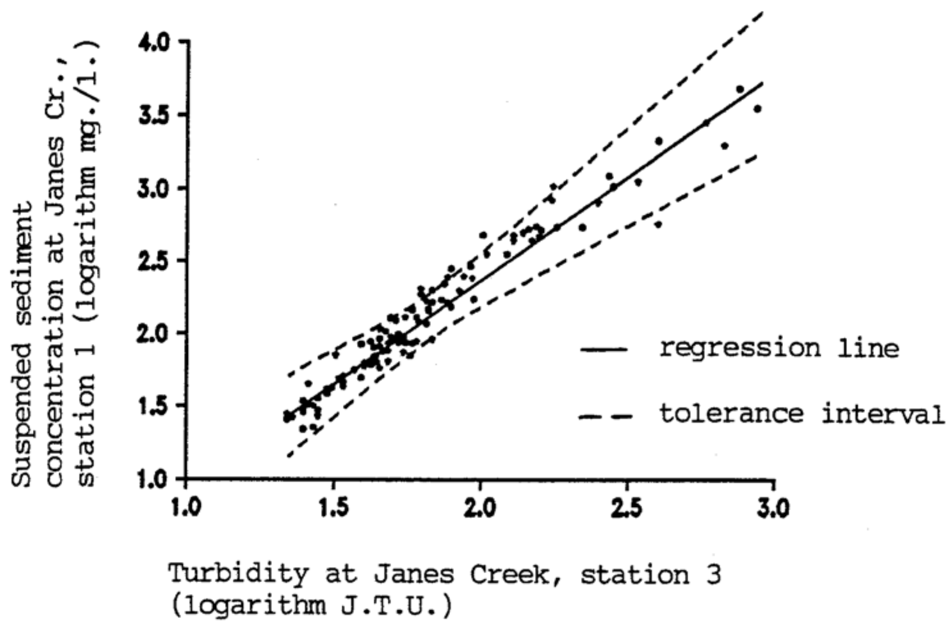

Figure 16. Suspended sediment concentrations at Janes Cr., station 1, regressed on simultaneous turbidity measurements at station 3. Tolerance bands cover at least 90% of normal distributions with 90% probability.

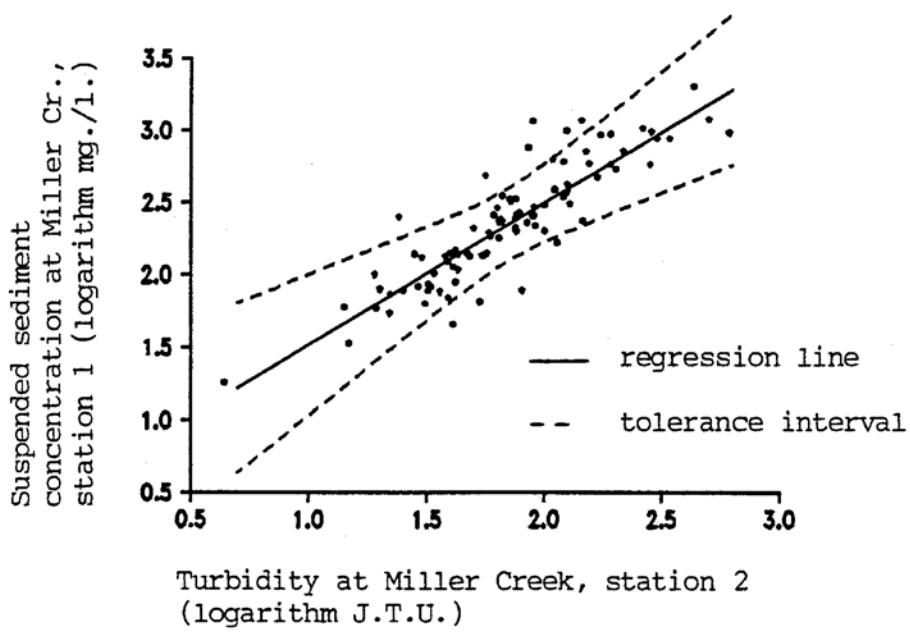

Figure 17. Suspended sediment concentrations at Miller Cr., station 1, regressed on simultaneous turbidity measurements at station 2. Tolerance bands cover at least 90% of normal distributions with 90% probability.

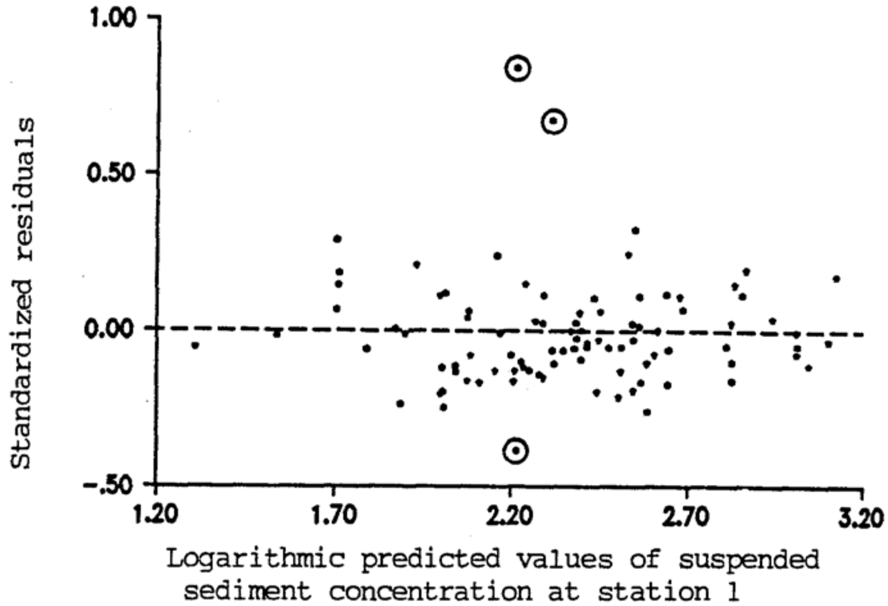

Figure 18. Standardized Residual Plot for the Logarithm of Suspended Sediment Concentration at Station 1 of Miller Creek. Large outliers are circled.

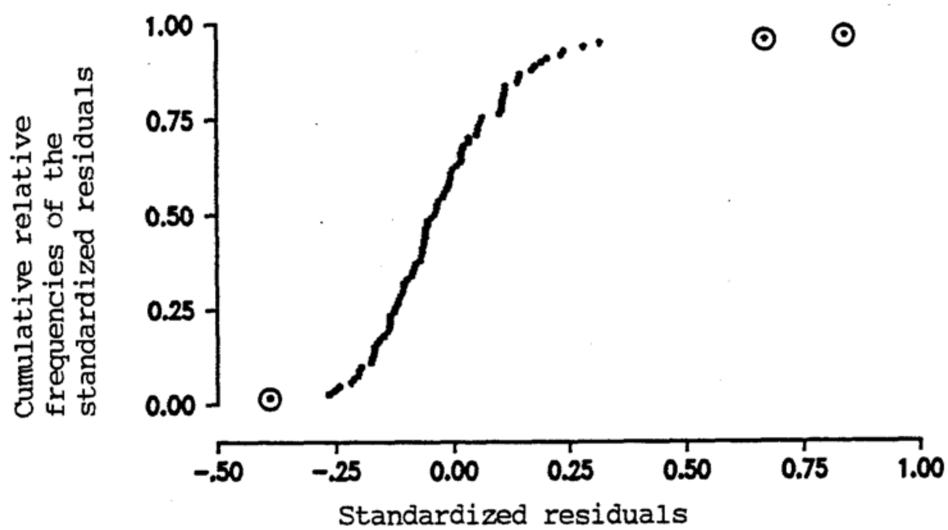

Figure 19. Normal Probability Plot for Suspended Sediment Concentration at Station 1 of Miller Creek. Large outliers are circled.

and L_TURB1 at Janes Creek and Miller Creek did not violate the assumptions of least squares linear regression analysis.

Cross-Validation of the Selected Model

The statistic "shrinkage on cross-validation," used to assess whether a chosen model will be a good predictor in a new sample, ranged from -.074 to .051 (table 8). Values less than .10 indicate a reliable model (Kleinbaum, et al. 1988).

Table 8. Cross-Validation between Initial Samples and Validation Samples from Janes Creek and Miller Creek Data Sets.

Sample	Dependent Variable	Independent Variables	r^2	"shrinkage on cross-validation"
initial	actual L_SUSP1	predicted L_SUSP1	.957	.029
validation	actual L_SUSP1	predicted L_SUSP1	.928	
initial	actual L_TURB1	predicted L_TURB1	.975	.051
validation	actual L_TURB1	predicted L_TURB1	.924	
initial	actual L_SUSP1	predicted L_SUSP1	.812	-.074
validation	actual L_SUSP1	predicted L_SUSP1	.886	
initial	actual L_TURB1	predicted L_TURB1	.809	.002
validation	actual L_TURB1	predicted L_TURB1	.807	

a) values were calculated using the regression equation from the initial sample.

DISCUSSION

Results of this study from Miller Creek did not support in-stream water quality standards' implicit assumption of uniform turbidity and suspended sediment concentrations along short, longitudinal stretches of an undisturbed stream. The average relative difference in turbidity levels along a 110.6 meter stretch of Miller Creek was 27.9 percent. This was 7.9 percent greater than the man-induced turbidity level increases allowed by California in-stream water quality regulations. The implications of this could be substantial.

Suppose that no preliminary data had been collected and water quality monitoring on a stream above and below a housing development showed turbidity increases of 26 percent. Since this is in excess of the 20 percent increase permitted by law, lawsuits could be filed, court orders given, and fines levied. It could have been possible, however, that half of that 26 percent increase was due to natural variation of turbidity levels in the stream. The results from the longitudinal variation seen at Miller Creek in northwestern California suggest that it would have been possible for the housing development to have caused only 13 percent of the 26 percent increase.

Once land adjacent to a given stretch of a stream has been disturbed, it is impossible to know the pre-disturbance turbidity variations. Obviously, in-stream turbidity or suspended sediment sampling must be carried out before land disturbance. This leads to the question of the number of samples necessary to characterize the longitudinal variation of water quality along a short stretch of an undisturbed stream. At Janes Creek, the characteristics of a subsample of 75 observations mirrored the larger sample of over 450 observations. At Miller Creek, the subsample of 96 observations also well represented the complete sample set. Subsamples smaller than 75 and 96 observations would be satisfactory so long as the regression estimates are not significantly affected by outliers.

The collection of measurements over a wide range of discharges is as important as the number of samples taken. At Janes Creek and Miller Creek, linear regression estimates based only on suspended sediment samples from low discharges would have been very different from linear regression estimates obtained from high discharge sampling. Since high discharges tend to occur infrequently, it is tempting to formulate a stream specific linear regression relationship based on suspended sediment samples from low discharges and then apply the relationship to high discharges. This type of extrapolation often grossly underestimates actual suspended sediment concentrations at high stream flows. Failure to sample over a wide range of discharges at Janes and Miller Creeks would have restricted the validity of a linear relationship to those discharges in which samples were taken.

Another reason for sampling during a wide range of discharges is to detect any changes in the size of relative differences in turbidity or suspended sediment concentration between two monitoring stations. At Janes Creek and Miller Creek relative differences did not increase during high discharges.

An important problem relating to the monitoring of a stream above and below a land disturbance such as a housing development concerns the use of turbidity as a measure of changes in delivery of suspended sediment. Suppose a small dam .40 kilometers downstream of the housing development was providing a heavily used fishing and swimming area. Housing tract land disturbances might lead to increased sediment loads to the stream. The resulting increase in suspended sediment in the stream would settle in the still waters of the reservoir and possibly reduce the reservoir to nothing more than a shallow wading pond. Turbidity readings taken from the stream before and after housing construction could not easily and directly be converted to volumes of sediment that accumulated behind the dam. Sediment volumes must be obtained from suspended sediment concentrations. Since the relationship between turbidity and suspended sediment concentration is stream specific and can vary from nearly perfect to none at all, monitoring of both water quality parameters before construction of the housing tract would be necessary in order to quantify a relationship for that particular reach of stream. Since the disturbance itself could affect the relationship between turbidity and suspended sediment, monitoring of water quality after construction might also be necessary. At Janes Creek and Miller Creek, the relationship between suspended sediment concentration at one point on the stream and turbidity a short distance upstream was not quite as strong as the relationship between suspended sediment concentrations measured at the same points. The relationship between turbidity and suspended sediment concentration on the stream adjacent to the housing development might be very poor, in which case turbidity readings before and after construction would be of little use in predicting the degree of siltation behind the dam.

Suppose that concerns over the siltation behind the dam and the potential loss of the reservoir resulted in the implementation of erosion control measures at the housing development located upstream. Assuming that this erosion protection reduced sediment loads to the stream, the method of measuring changes in stream water quality would have to be accurate. Results from Janes Creek and Miller Creek suggested that suspended sediment concentration might be more sensitive than turbidity to changes in water quality. Relative differences in suspended sediment concentrations between monitoring stations were, on the average, greater than relative differences in turbidity.

In light of concern over the possible siltation behind the dam with or without the upstream housing development, assume that several hydrologists were hired to study the variation in suspended sediment and turbidity along the .40 kilometer stretch of stream between the dam and the housing development for six months prior to any disturbance of the land or creek. The hydrologists constructed two monitoring stations along this 400 meter stream reach, one just below the spot where housing construction would end and one station just before the entrance to the small reservoir. The goal was not only to measure the differences between suspended sediment/turbidity between the two points, but to define a relationship between those quantities at the two points. The results from Janes Creek and Miller Creek suggest that the best type of model to predict suspended sediment/turbidity at the lower point would not be a time series model (which generally requires measurements taken at equal time intervals), but a linear regression between the logarithms of the suspended sediment concentration/turbidity sampled simultaneously at the two monitored points. The Janes and Miller Creek data suggests that a relationship between discharge and suspended sediment concentration developed for the site just above the reservoir would be inferior to the regression model described for Janes and Miller Creeks.

Developing suspended sediment/turbidity relationships for the stream next to the housing development would, of course, be a time consuming effort. It would be far easier to skip data collection and use regression relationships that have already been developed for a stream with physical characteristics similar to the stream under study. Although the regression model developed for Janes Creek is the same as the model developed for Miller Creek, the dissimiliar values of the coefficients $\hat{B}_0$ and $\hat{B}_1$ (table 7) suggest that the regression relationships are stream specific. Consider this in relation to the fact that both Miller Creek and Janes Creek are contained in watersheds with almost identical characteristics. Differences in climate, terrain, vegetation, and soil types between the two watersheds are extremely small. The only significant difference between the two streams is gradient; the average gradient of Miller Creek is twice that of Janes Creek. Even if this does account for the differences between the $\hat{B}_0$ and $\hat{B}_1$ coefficients of the regression equations developed for each creek, it would probably be erroneous to apply a regression equation developed on one stream to another stream of similar gradient. This type of simple-minded use of regression relationships is almost always inappropriate and leads to meaningless conclusions (Kleinbaum, et al. 1988).

Another problem with the linear regression model applied to the Janes Creek and Miller Creek data is that outlier observations were probably the result of natural stream processes. A piece of streambank could have fallen into the stream between the two suspended sediment monitoring stations just before the instant of sediment sampling. The upstream station never "saw" the sediment from streambank failure and recorded a relatively low suspended sediment concentration. The plume of sediment was then sampled at the downstream station, resulting in a high suspended sediment concentration. Since the presence of a few large outliers can destroy an otherwise good linear regression relationship, the linear regression model used for Janes and Miller Creeks might not work on a stream where streambank failures are frequent.

Conclusions

1.) At Miller Creek, the mean variation in turbidity and suspended sediment concentration was greater than the 20 percent man-induced increase allowed by California water quality standards. At Janes Creek, the mean variation in turbidity and suspended sediment concentration was a small fraction of the 20 percent standard; this variation was considered insignificant.

2.) At Janes Creek and Miller Creek, suspended sediment concentrations and turbidity readings at one point on a stream were best predicted by values of those parameters taken simultaneously a short distance upstream; prediction of turbidity and suspended sediment concentration from discharge alone was not nearly as accurate. The knowledge of discharge and variables related to discharge did not significantly aid in predictions of turbidity and suspended sediment concentration above predictions made strictly on the basis of upstream turbidity and suspended sediment concentration.

3). Predictions of suspended sediment concentrations at one point on a stream based on turbidity measurements a short distance upstream were slightly less accurate than predictions made from upstream suspended sediment concentrations.

4.) Although the form of the model that best predicted the data sets on Janes Creek and Miller Creek was the same, the numerical coefficients of the regression equations from the two streams were different. It is probable that the gradient difference between Janes Creek and Miller Creek was at least partially responsible for the differing regression coefficients. Assuming that the general model used here could be applied to other streams, new regression equations would have to be developed. It is also possible that regression equations developed on one short stretch of a stream would be valid only for those particular stations.

Recommendations

Conclusions based on the data from Janes Creek and Miller Creek suggested the following recommendations regarding the subject of above and below stream monitoring.

1.) Since the variation in turbidity and suspended sediment concentration along a short stretch of an undisturbed stream may or may not be significant, it is necessary to measure that variation before land adjacent to the reach of stream is disturbed.

2.) There is no absolute "correct" number of observations that are necessary to monitor in-stream water quality above and below a future land disturbance. If regression analysis is applied to the data, a minimum sample size of 30 + 2P, where P is the number of estimators, is suggested (Kleinbaum, et al. 1988). Observations should be taken either a) simultaneously at each monitoring site, or b) with some fixed lag in sampling times between stations. At least half of the samples should come from periods of high stream discharges. The observations should come from several storm events in order to include variation across storms as well as within storms. The same recommendations would hold true for monitoring of water quality after the land disturbance.

3.) If a linear regression model is fit to the data, sampling need not be done at equal time intervals.

4.) Prediction of suspended sediment concentrations from turbidity can only be done if pre-disturbance monitoring shows a high correlation between turbidity and suspended sediment concentration. Even if correlation is high, predictions of suspended sediment concentrations from upstream turbidity measurements will be poorer than predictions based on suspended sediment concentrations upstream.

5.) If sediment discharge or flood control information is not of concern, measurements of water discharge may not be necessary. At Janes Creek and Miller Creek, sediment rating curve predictions and actual suspended sediment concentrations differed, on the average, by 30-55 percent. Predictions of suspended sediment concentration based on an upstream concentration differed from actual suspended sediment concentrations by less than 20 percent.

6.) All stream specific regression relationships should be tested for conformity to the basic assumptions of linear regression analysis. The assumptions of homoscedasticity, linearity, and normality of error terms, in particular, must be satisfied.

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A P P E N D I X E S

APPENDIX A. Sample Data Sets for Janes Creek and Miller Creek Used to to Develop a Linear Regression Model.

SUSP1 : suspended sediment concentration in mg./l. at station 1 (downhill or "lower" station).
SUSP2 : suspended sediment concentration in mg./l. at station 2 {upstream station at Miller Creek}.
SUSP3 : suspended sediment concentration in mg./l. at station 3 (upstream station at Janes Creek).
TURB1 : turbidity in J.T.U. at station 1.
TURB3 : turbidity in J.T.U. at station 3.
FLOW : instantaneous discharge ,($m.^3/s.$) at station 1.
CFLOW : cumulative discharge ($m.^3/s.$) during a specific storm.
MFLOW : maximum discharge ($m.^3/s.$) at station 1.
MONTH : month of the hydrologic year of a specific storm's occurence (August=1, September=2, etc.).

Janes Creek

SUSP3	SUSP1	TURB3	TURB1	FLOW	CFLOW	MFLOW	MONTH
196.86	213.53	75	74	0.084900	0.2824	0.115747	9
204.38	157.60	68	61	0.093673	0.6308	0.115747	9
218.05	234.81	77	75	0.107257	1.0293	0.115747	9
198.62	191.64	68	67	0.112351	1.4736	0.115747	9
171.06	160.59	65	59	0.105559	1.9244	0.115747	9
125.91	99.07	47	44	0.088296	2.3039	0.115747	9
457.03	422.59	148	140	0.063958	0.1825	0.367627	8
215.47	230.58	93	83	0.063858	0.4469	0.367617	8
123.96	138.36	66	61	0.054902	0.6789	0.367617	8
87.75	95.06	52	50	0.056600	0.8968	0.367617	8
81.44	90.76	49	48	0.060279	1.1269	0.367617	8
136.53	180.06	62	73	0.072731	1.3983	0.367617	8
498.58	527.70	153	141	0.095371	1.7359	0.367617	8
479.79	478.39	138	132	0.097069	2.1412	0.367617	8
620.68	497.12	159	134	0.105559	2.5447	0.367617	8
5431.57	4723.26	750	720	0.245078	3.3219	0.367617	8
4520.89	3464.13	860	820	0.356863	4.5594	0.367617	8
2150.30	2739.34	580	590	0.344411	5.9849	0.367617	8
1228.80	2066.46	400	380	0.236588	7.1534	0.367617	8
760.66	1179.14	270	251	0.163008	7.8903	0,367617	8
582.37	986.98	175	165	0.145462	8.4925	0.367617	8
402.14	505.52	144	137	0.18860	9.0116	0.367617	8
115.13	337.85	104	100	0.108955	8.4610	0.367617	8
211.87	237.37	87	88	0.095371	9.8594	0.367617	8
195.44	270.15	79	79	0.089994	10.2254	0.367617	8
157.16	195.00	62	61	0.084900	10.5700	0.367617	8

SUSP3	SUSP1	TURB3	TURB1	FLOW	CFLOW	MFLOW	MONTH
121.21	118.53	51	63	0.077825	10.8924	0.367617	8
121.74	123.73	49	57	0.074429	11.1969	0.367617	8
84.60	77.36	43	41	0.068052	11.4788	0.367617	8
92.05	84.81	42	41	0.065656	11.7431	0.367617	8
215.40	189.15	84	75	0.027734	0.0498	0.038771	7
172.16	164.28	73	76	0.038771	0.1899	0.038771	7
108.87	123.87	55	59	0.036790	0.3410	0.038771	7
80.94	103.87	45	47	0.035092	0.4814	0.038771	7
59.45	81.50	39	39	0.031413	0.6104	0.038771	7
61.95	66.45	43	38	0.029432	0.7341	0.038771	7
137.28	112.56	65	66	0.088296	0.3656	0.086598	10
96.00	87.71	51	53	0.079806	0.6967	0.086598	10
81.38	59.22	42	43	0.071033	0.9962	0.086598	10
74.51	48.09	39	39	0.069052	1.2727	0.086598	10
55.33	54.15	37	36	0.061977	1.5333	0.086598	10
49.58	47.23	33	32	0.058581	1.7764	0.086588	10
43.36	40.00	30	30	0.056600	2.0085	0.086598	10
49.66	37.17	30	31	0.056600	2.2315	0.086598	10
37.34	34.57	28	28	0.056600	2.4579	0.086598	10
34.75	30.76	27	26	0.053204	2.6724	0.086588	10
33.31	28.20	25	26	0.051223	2.8773	0.086598	10
31.75	33.21	25	27	0.047827	3.0737	0.086598	10
29.47	29.66	25	25	0.045846	3.2610	0.086598	10
29.99	25.56	23	23	0.044148	3.4427	0.086588	10
37.34	26.95	22	22	0.042167	3.6153	0.086588	10
212.68	166.57	94	89	0.067354	0.2943	0.079806	10
124.14	87.99	68	65	0.053204	0.5267	0.079806	10
82.29	67.66	57	55	0.053204	0.7392	0.079806	10
66.84	61.94	48	48	0.049525	0.9407	0.079806	10
547.27	523.71	220	209	0.081504	0.2926	0.345543	7
905.49	*	300	289	0.114049	0.7064	0.345543	7
1463.82	548.65	400	360	0.222155	1.3349	0.345543	7
2524.95	1911.85	670	640	0.345543	2.6543	0.345543	7
1153.31	1003.22	280	320	0.331676	4.0146	0.345543	7
692.43	803.14	173	198	0.275076	5.2542	0.345543	7
395.95	455.54	128	132	0.145462	5.9455	0.345543	7
*	460.73	101	113	0.122256	6.4632	0.345543	7
364.43	338.72	122	112	0.063958	0.1738	0.169234	6
144.19	139.67	58	70	0.063958	0.4364	0.169234	6
87.68	71.65	54	50	0.051223	0.6540	0.169234	6
64.60	58.51	42	42	0.043016	0.8368	0.169234	6
82.68	55.41	45	40	0.040469	0.9987	0.169234	6
1594.18	1081.33	340	240	0.086598	1.2565	0.169234	6
1127.77	777.15	248	260	0.169234	1.8788	0.169234	6
430.26	422.66	128	140	0.153386	2.5133	0.169234	6
265.68	280.59	92	100	0.103861	3.0072	0.169234	6
234.99	147.08	79	70	0.079806	3.3589	0.169234	6
152.31	142.25	58	70	0.065656	3.6459	0.169234	6
139.66	82.94	52	20	0.054902	3.8836	0.169234	6

Miller Creek

SUSP2	SUSP1	TURB2	TURB1	FLOW	CFLOW	MFLOW	MONTH
930.59	905.23	172	215	1.17558	4.1977	1.28680	5
611.81	1133.18	143	164	1.25850	8.8500	1.28680	5
592.92	918.24	190	203	1.28680	13.6740	1.28680	5
*	690.37	149	*	0.97126	17.8862	1.28680	5
*	308.49	72	*	0.79014	21.3577	1.28680	5
259.53	467.17	56	99	0.66845	24.1308	1.28680	5
148.97	230.16	145	173	0.59430	26.5627	1.28680	5
127.49	963.60	124	154	0.52497	28.7650	1.28680	5
95.25	1126.15	89	122	0.54194	30.8654	1.28680	5
111.44	195.15	100	123	0.47657	32.8518	1.28680	5
81.59	246.22	90	102	0.44572	34.6961	1.28680	5
*	75.69	80	*	0.41969	36.4040	1.28680	5
22.71	70.70	22	46	0.02268	0.0468	0.43582	7
22.43	97.09	19	59	0.02243	0.1381	0.43582	7
22.83	77.33	20	44	0.02603	0.2441	0.43582	7
321.11	562.54	190	260	0.18087	0.5868	0.43582	7
235.79	587.41	120	250	0.37639	1.7779	0.43582	7
119.15	250.29	61	95	0.42082	3.4730	0.43582	7
64.80	135.64	40	65	0.33168	4.9438	0.43582	7
51.24	125.87	30	70	0.26715	6.1040	0.43582	7
38.82	75.63	25	40	0.25377	7.1139	0.43582	7
161.37	199.19	75	85	0.32205	1.3137	0.44572	7
127.90	176.84	59	108	0.29800	2.5295	0.44572	7
103.17	241.40	24	129	0.33479	3.7942	0.44572	7
152.84	206.69	75	94	0.32205	5.1079	0.44572	7
161.77	247.49	88	113	0.28611	6.3117	0.44572	7
118.15	136.42	57	66	0.26376	7.4225	0.44572	7
91.49	129.73	55	65	0.25272	8.4665	0.44572	7
106.41	131.11	54	62	0.27479	9.4890	0.44572	7
244.45	363.67	125	165	0.32205	10.7299	0.44572	7
259.17	373.56	110	125	0.37413	12.1090	0.44572	7
543.49	696.80	215	250	0.41629	13.7897	0,44572	7
300.75	408.04	125	125	0.41629	15.4549	0.44572	7
222.94	282.95	90	100	0.41629	17.1634	0.44572	7
168.77	226.31	64	95	0.38799	18.7431	0.44572	7
185.45	257.11	77	95	0.40186	20.3505	0.44572	7
245.69	323.23	75	95	0.44572	22.0168	0.44572	7
292.00	332.99	120	130	0.43073	23.7847	0.44572	7
179.09	341.22	66	75	0.41629	25.4355	0.44572	7
155.26	252.80	76	90	0.40186	27.0573	0.44572	7
139.59	188.46	58	67	0.37413	28.5954	0.44572	7
159.65	278.67	63	81	0.63081	2.6599	2.00873	4
83.96	142.73	42	51	0.52497	4.8801	2.00873	4
58.50	80.05	33	41	0.49242	6.8339	2.00873	4
53.51	133.01	28	34	0.46101	8.7249	2.00873	4
42.41	135.37	28	38	0.41628	10.4636	2.00873	4
51.48	61.22	31	35	0.44572	12.2468	2.00873	4

SUSP2	SUSP1	TURB2	TURB1	FLOW	CFLOW	MFLOW	MONTH
52.29	75.26	32	41	0.47657	14.1067	2.00873	4
64.21	128.24	38	50	0.54194	16.1810	2.00873	4
65.83	98.79	34	43	0.55892	18.4097	2.00873	4
118.35	202.53	50	77	0.66845	20.9344	2.00873	4
758.32	939.57	610	81	1.28680	24.9309	2.00873	4
1203.27	1157.07	500	340	1.72375	31.1809	2.00873	4
925.81	850.00	300	280	1.93515	38.9595	2.00873	4
368.13	561.55	280	230	1.79252	46.2351	2.00873	4
545.88	525.22	200	195	1.59103	52.9334	2.00873	4
1025.02	850.15	340	340	1.79252	60.2974	2.00873	4
547.45	460.07	167	140	1.59103	66.8593	2.00873	4
327.51	379.48	110	120	1.46481	72.8117	2.00873	4
326.56	294.43	100	107	1.28680	78.3115	2.00873	4
262.97	250.42	90	93	1.12238	83.1267	2.00873	4
245.99	223.54	84	84	0.94748	87.1374	2.00873	4
218.66	193.69	76	77	0.79014	90.5195	2.00873	4
182.99	174.30	64	74	0.74825	93.6175	2.00873	4
277.51	211.37	91	92	0.72788	96.6739	2.00873	4
7.23	17.61	4	6	0.00679	0.0125	0.64948	6
22.39	58.19	14	13	0.01472	0.0563	0.64948	6
37.40	44.05	41	44	0.02943	0.1656	0.64948	6
52.42	63.44	53	57	0.05915	0.4072	0.64948	6
129.84	162.17	113	113	0.13556	0.9447	0.64948	6
35.96	74.23	36	52	0.15876	1.5327	0.64948	6
28.43	52.78	21	38	0.13556	2.1375	0.64948	6
13.92	32.77	14	23	0.12141	2.6441	0.64948	6
201.12	259.55	78	100	0.21197	3.3284	0.64948	6
275.00	299.38	128	127	0.30988	4.3961	0.64948	6
188.53	320.72	71	122	0.38799	5.8273	0.64948	6
222.53	237.18	75	106	0.52497	8.1379	0.64948	6
94.38	118.72	39	52	0.47657	10.1405	0.64948	6
93.80	109.23	41	49	0.41629	11.8942	0.64948	6
64.16	80.50	29	35	0.37413	13.4600	0.64948	6
53.06	57.10	19	22	0.36083	14.9432	0.64948	6
559.69	948.96	284	201	1.02022	3.0117	1.62357	6
1283.55	1965.77	430	450	1.62357	8.3406	1.62357	6
926.28	1001.53	260	250	1.43396	14.1709	1.62357	6
522.58	568.44	154	158	1.14898	18.0680	1.62357	6
358.21	604.10	108	112	0.94748	23.2032	1.62357	6
250.36	738.04	85	87	0.83315	26.7158	1.62357	6
168.81	233.16	65	66	0.72788	28.7098	1.62357	6
156.15	226.11	66	66	0.63081	32.3466	1.62357	6
115.16	135.69	47	52	0.57647	34.7425	1.62357	6
99.55	132.43	43	46	0.57647	37.0133	1.62357	6
101.39	128.88	48	52	0.57647	39.2841	1.62357	6
80.44	104.28	43	48	0.54194	41.5034	1.62357	6
71.00	86.42	42	36	0.50855	43.5220	1.62357	6
96.13	67.06	39	32	0.49242	45.5078	1.62357	6
58.34	83.60	32	29	0.46101	47.3830	1.62357	6

APPENDIX B. Observed and Predicted Values of Suspended Sediment Concentration and Turbidity for Station 1 at Janes Creek.

Obs. = Observation number

Susp1 = Observed suspended sediment concentration in mg./l. at station 1. (Values are the same as those in Appendix B.)

S_pred = Predicted suspended sediment concentration (mg./l.) at station 1, based on observed concentration at station 2. (Equation L_SUSP1 = -.0026 + .990L_SUSP3 from Table 6 was used to calculate the logarithmic value of S_pred; conversion of the logarithmic estimate is described on page 25.)

S pred@t = Predicted suspended sediment concentration (mg./l.) at station 1, based on observed turbidity (J.T.U.) at station 2. (Equation L_SUSP1 = -.494 + 1.430L_TURB3 from Table 6 was used to calculate the logarithmic value of S_pred@t; conversion of the logarithmic estimate is described on page 25.)

Turb1l = Observed turbidity (J.T.U.) at station 1. (Values are the same as those listed in Appendix B.)

T pred = Predicted turbidity (J.T.U.) at station 1, based on observed turbidity at station 2. (Equation L_TURB1 = .0246 + .983L_TURB3 from Table 6 was used to calculate the logaithmic value of T_pred; conversion of the logarithmic estimate is described on page 25.

Obs.	Susp1	S_pred	S_pred@t	Turb1	T_pred
1	213.53	188.11	156.40	74	74
2	157.60	195.22	135.95	61	67
3	234.91	208.15	162.40	75	75
4	191.64	189.78	135.95	67	67
5	160.59	163.69	127.46	59	64
6	99.07	120.85	80.17	44	46
7	422.59	433.06	413.40	140	144
8	230.58	205.71	212.73	83	91
9	138.36	119.00	130.27	61	65
10	95.06	84.53	92.64	50	51
11	90.76	78.51	85.09	48	48
12	180.06	130.94	119.13	73	61
13	527.70	472.02	433.52	141	149
14	478.39	454.40	374.05	132	134
15	497.12	586.33	458.04	134	154
16	4723.26	5020.84	4209.57	720	711
17	3464.13	4186.70	5119.56	820	814
18	2739.34	2006.20	2914.76	590	552
19	2066.46	1152.88	1713.35	380	383

OBS.	Susp1	S_pred	S_pred@t	Turb1	T_pred
20	1179.14	717.10	976.68	251	260
21	996.98	550.49	525.34	165	170
22	505.52	381.53	397.52	137	140
23	337.85	110.61	249.61	100	102
24	237.37	202.31	193.38	88	85
25	270.15	186.77	168.46	79	77
26	195.00	150.51	119.13	61	61
27	118.53	116.39	90.10	63	50
28	123.73	116.89	85.09	57	48
29	77.36	81.53	70.59	41	42
30	84.81	88.63	68.26	41	41
31	189.15	205.64	183.92	75	82
32	164.28	164.73	150.47	76	72
33	123.87	104.65	100.37	59	54
34	103.87	78.03	75.33	47	44
35	81.50	57.49	61.39	39	38
36	66.45	59.89	70.59	38	42
37	112.56	131.65	127.46	66	64
38	87.71	92.39	90.10	53	50
39	59.22	78.45	68.26	43	41
40	48.09	71.89	61.39	39	38
41	54.15	53.55	56.94	36	36
42	47.23	48.03	48.35	32	33
43	40.00	42.06	42.19	30	30
44	37.17	48.11	42.19	31	30
45	34.57	36.28	38.22	28	28
46	30.76	33.79	36.29	26	27
47	28.20	32.40	32.51	26	25
48	33.21	30.90	32.51	27	25
49	29.66	28.70	32.51	25	25
50	25.56	29.20	28.85	23	23
51	26.95	36.28	27.07	22	22
52	166.57	203.07	216.01	89	92
53	87.99	119.17	135.95	65	67
54	67.66	79.32	105.63	55	56
55	61.94	64.56	82.62	48	47
56	523.71	517.63	728.73	209	213
57	*	852.15	1135.49	289	289
58	548.65	1370.99	1713.35	360	383
59	1911.85	2351.96	3582.51	640	637
60	1003.22	1082.75	1028.81	320	270
61	803.14	653.39	516.78	198	168
62	455.54	375.72	335.90	132	125
63	460.73	*	239.37	113	99
64	338.72	346.10	313.61	112	119
65	139.67	138.21	108.29	70	57
66	71.65	84.46	97.77	50	53
67	58.51	62.42	68.26	42	41
68	55.41	79.69	75.33	40	44
69	1081.33	1491.80	1358.04	240	327
70	777.15	1059.01	864.90	260	239
71	422.66	407.94	335.90	140	125

Obs.	Susp1	S_pred	S_pred@t	Turb	T_pred
72	280.59	253.11	209.47	100	90
73	147.08	224.15	168.46	70	77
74	142.25	145.92	108.29	70	57
75	82.94	133.91	92.64	20	51

APPENDIX C. Observed and Predicted Values of Suspended Sediment Concentration and Turbidity for Station 1 at Miller Creek.

Obs. = Observation number

Susp1 = Observed suspended sediment concentration in mg./l. at station 1. (Values are the same as those in Appendix B.)

S_pred = Predicted suspended sediment concentration (mg./l.) at station 1, based on observed concentration at station 2. (Equation L_SUSP1 = .600 + .807L_SUSP2 from Table 6 was used to calculate the logarithmic value of S_pred; conversion of the logarithmic estimate is described on page 25.)

S_pred@t = Predicted suspended sediment concentration (mg./l.) at station 1, based on observed turbidity (J.T.U.) at station 2. (Equation L_SUSP1 = .534 + .982L_TURB2 from Table 6 was used to calculate the logarithmic value of S_pred@t; conversion of the logarithmic estimate is described on page 25.)

Turb1 = Observed turbidity (J.T.U.) at station 1. (Values are the same as those listed in Appendix B.)

T_pred = Predicted turbidity (J.T.U.) at station 1, based on observed turbidity at station 2. (Equation L_TURB1 = .503 + .769L_TURB2 from Table 6 was used to calculate the logarithmic value of T_pred; conversion of the logarithmic estimate is described on page 25.

Obs.	Susp1	S_pred	S_pred@t	Turb1	T_pred
1	905.23	1027.03	558.84	215	202
2	1133.18	732.14	466.16	164	164
3	918.24	713.84	616.22	203	193
4	690.37	*	485.36	*	*
5	308.49	*	237.63	*	*
6	467.17	366.47	185.66	99	111
7	230.16	234.14	472.57	173	171
8	963.60	206.50	405.27	154	156
9	1126.15	163.21	292.62	122	130
10	195.15	185.25	328.09	123	131
11	246.22	144.04	295.85	102	114
12	75.69	*	263.53	*	*
13	70.70	51.32	74.18	46	61
14	97.09	50.81	64.23	59	74
15	77.33	51.54	67.55	44	59
16	562.54	435.17	616.22	260	234
17	587.41	339.17	392.42	250	227
18	250.29	185.52	201.93	95	107

Obs.	Susp1	S_pred	S.pred@t	Turb1	T_pred
19	135.64	119.60	133.42	65	80
20	125.87	98.96	100.58	70	85
21	75.63	79.10	84.10	40	55
22	199.19	249.75	247.35	85	99
23	176.84	207.03	195.42	108	119
24	241.40	174.07	80.79	129	136
25	206.69	239.04	247.35	94	107
26	247.49	250.25	289.39	113	123
27	136.42	195.52	188.92	66	81
28	129.73	157.99	182.40	65	80
29	131.11	178.47	179.15	62	77
30	363.67	349.19	408.48	165	165
31	373•56	366.06	360.29	125	133
32	696.80	665.42	695.75	250	227
33	408.04	412.77	408.48	125	133
34	282.95	324.18	295.85	100	112
35	226.31	258.95	211.67	95	107
36	257.11	279.42	253.82	95	107
37	323.23	350.62	247.35	95	107
38	332.99	403.05	392.42	130	137
39	341.22	271.66	218.17	75	90
40	252.80	242.09	250.59	90	103
41	188.46	222.17	192.17	67	82
42	278.67	247.60	208.43	81	95
43	142.73	147.41	139.97	51	66
44	80.05	110.12	110.45	41	56
45	133.01	102.48	94.00	34	48
46	135.37	84.95	94.00	38	53
47	61.22	99.33	103.88	35	50
48	75.26	100.59	107.17	41	56
49	128.24	118.72	126.87	50	65
50	98.79	121.13	113.74	43	58
51	202.53	194.46	166.11	77	91
52	939.57	870.63	1937.29	81	95
53	1157.07	1263.71	1593.64	340	287
54	850.00	1022.77	965.01	280	247
55	561.55	485.91	901.80	230	213
56	525.22	667.87	648.05	195	187
57	850.15	1110.34	1091.22	340	287
58	460.07	669.32	542.88	140	145
59	379.48	442.16	360.29	120	129
60	294.43	441.12	328.09	107	118
61	250.42	370.39	295.85	93	106
62	223.54	350.96	276.47	84	98
63	193.69	319.14	250.59	77	91
64	174.30	276.42	211.67	74	89
65	211.37	386.83	299.07	92	105
66	17.61	20.38	15.27	6	13
67	58.19	50.73	47.92	13	23
68	44.05	76.75	136.70	44	59
69	63.44	100.79	175.89	57	72
70	162.17	209.56	369.93	113	123

Obs.	Susp1	S_pred	S_pred@t	Turb1	T_pred
71	74.23	74.36	120.31	52	67
72	52.78	61.52	73.84	38	53
73	32.77	34.57	50.26	23	36
74	259.55	298.32	257.06	100	112
75	299.38	384.00	418.10	127	134
76	320.72	283.15	234.39	122	130
77	237.18	323.69	247.35	106	117
78	118.72	162.00	130.14	52	67
79	109.23	161.20	136.70	49	64
80	80.50	118.65	97.29	35	50
81	57.10	101.78	65.23	22	35
82	948.96	681.38	914.45	201	192
83	1965.77	1331.33	1374.25	450	357
84	1001.53	1023.19	838.50	250	227
85	568.44	644.68	501.35	158	159
86	604.10	475.32	353.85	112	122
87	738.04	355.99	279.70	87	100
88	233.16	259.12	214.92	66	81
89	226.11	243.21	218.17	66	81
90	135.69	190.22	156.31	52.0	67
91	132.43	169.13	143.24	46.0	61
92	128.89	171.64	159.58	52.0	67
93	104.28	142.40	143.24	48.0	63
94	86.42	128.75	139.97	36.0	51
95	67.06	164.42	130.14	32.0	46
96	83.60	109.88	107.17	29.0	43