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EFFECTS OF VEGETATIVE MANIPULATIONS ON SEDIMENT CONCENTRATIONS IN NORTH-CENTRAL ARIZONA

by

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STATEMENT BY AUTHOR

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ABSTRACT

The sediment rating curve (SRC) method was used to study the effects of vegetative manipulations on sediment concentrations on the Beaver Creek watersheds of north-central Arizona. A linear model was best in the analysis of streamflow-sediment relationships. The corrected linear model eliminated some bias of the linear model and improved prediction. Partitioning data by streamflow-generating events and hydrograph stages produced significantly different SRCs and increased the descriptive and predictive powers. Due to insufficient data at the high streamflow range, SRCs for the pinyon-juniper watersheds had low values of r_a^2. SRCs for the ponderosa pine watersheds produced better results. More overstory removal resulted in higher sediment concentrations.

INTRODUCTION

Estimating sediment yields from watersheds has long been an important method of predicting siltation rates in downstream reaches and sediment deposition in reservoirs (Grenney and Heyse, 1985). Sediment yield is also an index to the decrease of long term site productivity of these watersheds. Sediment is generally higher in clay, silt, and organic matter than in the soil from which they are derived; these particles and organic compounds have a great capacity for absorbing plant nutrients, pesticides, and other chemicals. Sediment is considered a major water pollutant in addition to industrial wastes, effluent from sewage treatment plants, and other point sources of pollution (Glymph, 1972; Lopes and Ffolliott, 1992). Sediment is the largest pollutant of surface water in the United states (Meyer, 1972). Suspended sediment is responsible for 80% of the deterioration of water quality (Anderson, et al., 1976). Sediment affects the suitability of water for consumption and industrial use. Increased sedimentation in small mountain streams can also have a detrimental impact on fisheries (Beschta, 1987).

Whereas sediment discharge (sediment load) is the most important parameter for reservoir siltation, sediment concentration is the primary factor of environmental concern (Grenney and Heyse, 1985). The runoff entering stream channels promptly after rainfall or snowmelt is termed direct runoff. It represents the integrated effects of most characteristics of a watershed and superimposed environment as they relate to sediment production (Vanoni, 1975). As streamflow is easier to measure, streamflow data usually have longer record than suspended sediment. Sediment concentration is often expressed

as the empirical function of streamflow in a sediment rating curve (SRC) or sediment transport curve. SRCs are frequently used to estimate missing data or extend records (USGS, 1972). SRCs can be used along with runoff-frequency data (flow duration curve) to calculate sediment yields, a process which is called the flow duration-sediment rating curve method (Crawford, 1991).

There are two major advantages of using SRCs to determine long-term sediment yields: (1) numerous short-term streamflow records which are available for drainage areas throughout the country; and, (2) many long-term precipitation records, which can be used (along with an assumed rainfall-runoff relationship) to extend these streamflow records (Vanoni, 1975). The SRC method is the simplest and widely accepted method for assessing changes in suspended sediment delivery process (Thomas, 1988) and estimating watershed sediment yields (Flaxman, 1972; Grenny and Heyse, 1985; Beschta, 1987).

Problem Statement

The Salt-Verde River Basin is a major water production area in Arizona (Fig. 1). Pinyon-juniper woodlands and ponderosa pine forests occupy nearly 50% of the basin. The ponderosa pine type yields nearly one-half of the total runoff in the basin and the pinyon-juniper type yields approximately 10% (Barr, 1956). Little is known about sediment transport on pinyon-juniper watersheds. The results of several sediment discharge formulas differed significantly from the measured values (Wigdor, 1994).

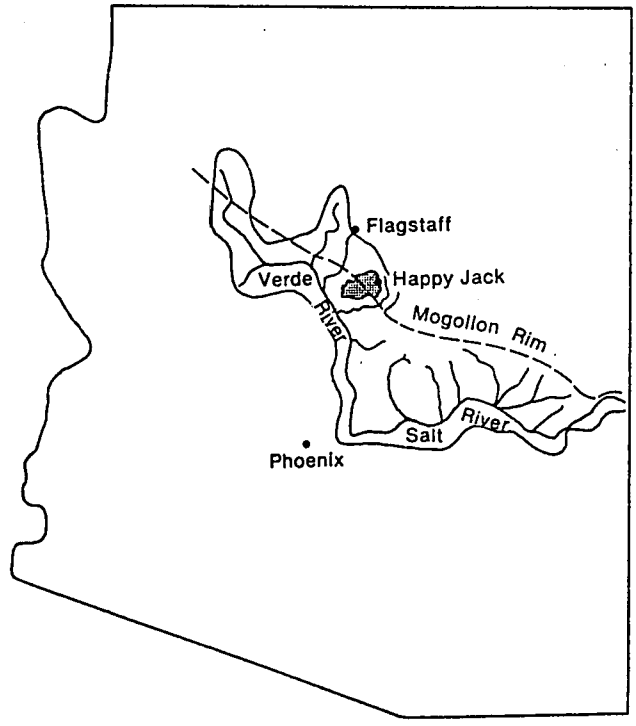


Figure 1. Location of the Beaver Creek Watershed

For the ponderosa pine watersheds, there is no convincing evidence to support that clearcutting produces higher sediment yields than other treatments, and that more basal area removal results in higher sediment yields. The soils, biotic systems, and sediment storage areas all confound the analysis. The major proportion of the sediment yield from the basalt-derived soils on the Beaver Creek experiment watersheds is suspended sediment (Ward and Baker, 1984). Sediment concentration is a useful index of watershed erosion. It is of concern how suspended sediment concentrations are related to streamflow discharge, streamflow-generating events, hydrograph stages (rising or falling limb), and how suspended sediment concentrations are affected by vegetative manipulations.

Objectives

This study was a part of the ongoing research on the hydrologic and sediment transport regimes of dryland forested watershed in Arizona. Streamflow-sediment relationships are being studied on the Beaver Creek watersheds, some of which were recovering after vegetative manipulations. The objectives of this study were (1) to evaluate different models of SRCs, (2) to test the improvement of SRCs when partitioning data by streamflow-generating events and hydrograph stages, and (3) to analyze the effects of vegetative manipulations on suspended sediment concentrations.

LITERATURE REVIEW

Sediment consists of the fragmented materials that originate from soil erosion. Sedimentation includes three basic processes: erosion, sediment transport, and deposition. Erosion is the detachment and initial displacement of soil, rock and organic matter by water and wind. Sediment transport is the movement of erosion products after initial displacement. Deposition is the temporary or permanent halting of the movement of transported products of erosion (Anderson, et al., 1976). Sediment yield is the amount of sediment leaving a specific area of land in a given period. Similarly, sediment discharge, or sediment load, is the amount of sediment passing a cross section in a given period.

Patric et al. (1984) summarized the sediment yield data from forested land in the United States. About 1/3 of their data from the eastern and western portions of the United States denoted annual sediment yields not exceeding 0.04 m-ton/ha (0.02 ton/ac) (m-ton is metric ton), and 3/4 of the total did not exceed 0.56 m-ton/ha (0.25 ton/ac). About 1/4 fell between 0.56 and 2.24 m-ton/ha (0.25 and 1.00 ton/ac) and some exceeded 2.24 m-ton/ha (1.00 ton/ac).

Studies on Sediment Yields on the Beaver Creek Watersheds

Due to water shortages in central Arizona, the Beaver Creek Watershed Evaluation Project was established in the late 1950s as a part of the Arizona Watershed Program. The objectives of the project were to evaluate the effects of vegetative

manipulations on water yield, erosion and sediment, forage and timber production, wildlife population, and recreational values (Brown, et al., 1974). Streamflow and precipitation gages were installed from the mid 1950s to the early 1960s to establish 20 experimental watersheds (sub-watersheds of the Beaver Creek watershed), 14 of which were in areas of ponderosa pine forests and 6 of which were in areas of pinyon-juniper woodlands. Total sediment yields had been measured by means of settling basins and flow splitters on Watersheds 1, 3, 9, 12, 14, 16, and 17, while suspended sediment had been measured by PS-69 pumping sampler on Watersheds 1, 2, 3, 8, 12, 13, 14, 19, and 20 (Ffolliott and Thorud, 1975; Ward and Baker, 1984).

Pinyon-Juniper Watersheds

Sediment yields from the control Watershed 2 (13 station years) varied from 0.02 to 0.60 m-ton/ha (0.01 to 0.27 ton/ac), with an average of 0.22 m-ton/ha (0.10 ton/ac) over a 9-year period. Winter and summer sediment yields ranged from trace (< 0.011 m-ton/ha, or 0.005 ton/ac) to 0.60 m-ton/ha (0.27 ton/ac), and from 0 to 0.60 m-ton/ha (0.27 ton/ac), respectively. Winter sediment yield was over 50%. Of the nine summer seasons of sediment measurement, only the sediment yield of 1970 was 0.60 m-ton/ha (0.27 ton/ac), the others having sediment yields of 0.011 m-ton/ha (0.005 ton/ac) or less (Clary, et al., 1974).

Sediment yields from treated watersheds varied from trace to 2.5 m-ton/ha (1.1 ton/ac) on the cabled Watershed 1 and from trace to 0.18 m-ton/ha (0.08 ton/ac) on the

herbicide-treated Watershed 3. The largest sediment yield of 2.5 m-ton/ha (1.1 ton/ac) was produced on Watershed 1 during the Labor Day storm of September 5, 1970, which had 10.3 cm (4.06 inches) of precipitation and produced the second largest peak streamflow of 8.75 $m^3/s/km^2$ (800 $ft^3/s/mi^2$) with an estimated return period of 100-150 years. The largest peak streamflow of 10.93 $m^3/s/km^2$ (1,000 $ft^3/s/mi^2$) occurred on August 3, 1964, when the total precipitation was 4.0 cm (1.59 inches) and the 30-minute intensity of 8.0 cm/hr (3.14 inch/hr) was the highest. These large events produced a major part of the sediment yields. An annual sediment yield of 2.2-4.5 m-ton/ha (1-2 ton/ac) approaches the maximum sediment loss potential for the pinyon-juniper watersheds with similar conditions (Clary, et al., 1974).

Shen and Li (1976) stated that sediment yields might not be increased by clearcut overstory if there is a proper management of ground cover. Overstory removal had little effect on either runoff or sediment yields on the Beaver Creek watersheds. Regression equations of sediment yields with seasonal runoff for both treated and untreated watersheds were as follows (Clary, et al., 1974):

winter:

$$Y = 0.0018PE_s - 2.24 \quad (r = 0.70) \tag{1}$$

summer:

$$Y = 0.0115PE_s \quad (r = 0.99) \tag{2}$$

where Y = sediment yield (m-ton/ha) (see Appendix A for a list of symbols used in this thesis).

PE_s= seasonal runoff (mm).

r = correlation coefficient.

Ponderosa Pine Watersheds

Annual sediment yields from untreated watersheds (26 station years) varied from a trace (<0.011 m-ton/ha, or 0.005 ton/ac) to 13 m-ton/ha (6 ton/ac), with an average of 1.3 m-ton/ha (0.6 ton/ac) over an 11-year period; but the average was only 0.04 m-ton/ha (0.02 ton/ac) excluding the Labor Day storm of 1970 (Brown, et al., 1974). Sediment yields from individual untreated watersheds ranged from trace to 25 m-ton/ha (11 ton/ac) during the 11-year period. The 25 m-ton/ha were derived from Watershed 10 during the Labor Day storm of 1970 that produced a peak streamflow discharge of 11.92 $m^3/s/km^2$ (1,090 $ft^3/s/mi^2$) (with an estimated recurrence interval of over 200 years) (Brown, et al., 1974).

Watershed 12 was clearcut during 1966-67. Annual sediment yields varied from 0.02 to 60.86 m-ton/ha (0.01 to 27.17 ton/ac). The largest yields of 19.69 and 60.86 m-ton/ha (8.79 and 27.17 ton/ac), in 1967 and 1970, respectively, resulted from abnormally high summer precipitation. The summer rainfall in 1967 was 31.3 cm (12.31 inches), about twice as much as the normal. It occurred at a critical time of watershed recovery, shortly after a timber harvesting operation. Rainfall on Labor Day of 1970 was 13-2 cm (5.1-7.0 inches), a storm with a return period of 100 years, which almost exclusively produced the sediment yield of that year (Ward and Baker, 1984).

On the stripcut Watershed 9, with the basal area of 19 m^2/ha (81 ft^2/ac), annual sediment yields varied from 0.02 to 2.9 m-ton/ha (0.01 to 1.3 ton/ac). On the heavily thinned Watershed 17, with a 6.9 m^2/ha (30 ft^2/ac) basal area, sediment ranged from 0.07 to 0.72 m-ton/ha (0.03 to 0.32 ton/ac) (Brown, et al., 1974). Winter sediment yields on all watersheds ranged from trace to 0.13 m-ton/ha (0.06 ton/ac) with a mean of 0.04 m-ton/ha (0.02 ton/ac) (Baker, 1975).

Sedimentation is primarily a result of snowmelt, with high intensity summer events infrequently producing large amounts of sediment. The soils on the Beaver Creek watersheds are fairly stony with a clay matrix. Snowmelt runoff has insufficient energy to dislodge and transport the fine sediments, but the big summer thunderstorms, though rare, are highly erosive and a large portion of the watersheds contributes sediment yield. The forested watersheds possess numerous storage zones on slopes and in channels where sediments accumulate from more frequent but less intense runoff events. The storage zones are potential sources of sediment for the larger events. Sediment yields are low except for large summer thunderstorm or snowmelt. Severe reductions in overstory basal area can lead to higher sediment yields (Ward and Baker, 1984).

Methods to Predict Sediment Yield

Estimates of sediment yields can be obtained by streamflow sampling, reservoir surveys, sediment rating curves (SRCs), empirical equations, and mathematical models. Many sediment prediction methods are based on the streamflow-sediment relationship that exists on any given watershed (Glymph, 1972; Vanoni, 1975).

Streamflow Sampling

Streamflow sampling involves measuring streamflow and (usually suspended) sediment concentrations, then calculating the sediment yield. Present streamflow sampling methods are costly, and the suspended sediment obtained should be adjusted upward to include bed load (Vanoni, 1975).

Reservoir Surveys

Reservoir sediment surveys include office work, laboratory analysis of sediment samples, field measurements, and processing and analysis of data (United States Army Corps of Engineers, 1961). Reservoir surveys provide a composite record of sediments from the upstream drainage area. The measured sediment yield is adjusted for reservoir trap efficiency. This method is especially useful in reservoir design. As it lumps the sediment yield from the watershed during one year or several years, the method's limitation is in estimating the effects of watershed management on sediment yields (Glymph, 1972).

Empirical Equations

Most empirical equations are expressed in terms of annual, monthly, or seasonal relationships between sediment yields and affecting variables. A regression equation relating sediment concentrations and runoff for a cultivated watershed in Texas was expressed by Baird (1964) as:

$$\log C = 0.5340 \log PE_h + 3.6736 \tag{3}$$

where PE_h = hourly runoff (mm).

Where there is a paucity of sediment and streamflow data, one can rely on calculation of sheet erosion through various equations, with adjustment for added erosion sources (gully, channel, etc.). A delivery ratio is then applied to determine the sediment yields to any given downstream point (Vanoni, 1975):

$$D = \frac{Y}{T} \tag{4}$$

where D = sediment delivery ratio.

Y = annual sediment yield at the measuring point (m-ton/ha).

T = total material eroded annually from the watershed and drainage system upstream from the measuring point (m-ton/ha).

The sediment delivery ratio method has a rationale for estimating management effects. Sediment delivery ratios have been developed for much of the eastern half of the United States, but little rainfall data and other complex factors have precluded the use of the method in the west (Glymph, 1972).

Mathematical Models

Mathematical models are hypothetical or stylized representations of the physical processes occurring during the erosion and transport of sediment from a watershed. For an infinitely wide one-dimensional streamflow, a differential equation can form the mathematical basis for modeling of sediment yield (Bennett, 1974):

$$\frac{\partial(hC)}{\partial t} + (1-\lambda)\frac{\partial y}{\partial t} + \frac{\partial(hV_s)}{\partial x} = \frac{\partial}{\partial x} hE_s \frac{\partial c}{\partial x} \tag{5}$$

where h = depth of streamflow (m).

t = time (s).

λ = porosity of deposited sediment.

y = local bed elevation (m).

V_s = average velocity of sediment (m/s).

x = distance positive in the direction of streamflow (m).

E_s = sediment particle mass transfer coefficient (m^2/s).

Bedload functions are developed for calculating the rate and quantity of movement of materials contributing to the bed of alluvial channels. Bedload functions often give widely different results for the same condition (Glymph, 1972).

Sediment Rating Curves (SRCs)

Sediment transport is influenced by hydrologic and hydraulic factors. These factors include streamflow, quantity and distribution of precipitation, streamflow-generating events, geologic structure, soil, topography, vegetation, and land-use. Semi-

empirical or empirical methods are often used, and one or two of the following factors are included: streamflow discharge, shear stress, velocity, and energy or water surface slope (McBean and Al-Nassri, 1988; Yang, 1988). The SRC method is one of the best methods.

A study by Campbell and Bauder (1940) on the Red River in Texas provides an early documented example of the use of SRCs in the United States. These authors were primarily interested in using SRCs for a daily sampling program in the calculation of sediment discharge. A subsequent report by Miller (1951) described an analysis of sediment yields from the San Juan River. He was concerned with applying an SRC derived from a short period of sediment measurements for estimating long term sediment discharge. The SRC technique has since been widely applied in estimating sediment yields both for large watersheds (Livesey, 1972) and for small- and medium-sized watersheds (Piest, 1963; Walling, 1977).

The relationship of streamflow and sediment can be expressed as a power function:

$$Y = aQ^b \tag{6}$$

where Y = sediment concentration (mg/l) or sediment discharge (sediment load) (m-ton/day, m-ton/month, etc.).

a = parameter, which can be taken as an index of relative erodibility.

Q = streamflow discharge (m^3/s).

b = slope of the curve in logarithmic scale.

The streamflow-sediment relationship is linear when taking the logarithm of the power function; common or natural logarithm transformation can used:

$$\log Y = \log a + b \log Q \tag{7}$$

or

$$Y' = a' + bQ \tag{8}$$

The equation or its plot is referred to as the sediment rating curve (SRC), or sediment transport curve.

Classification of SRCs

SRCs can be classified according to the following criteria: form of streamflow-sediment relationship, period of basic data, type of sediment, or variables.

Form of streamflow-sediment relationship. The streamflow-sediment relationship is linear for the above SRCs. In some cases, after log-transformation, the streamflow-sediment relationship may still not be linear, and a quadratic model can be fitted (Neter, et al., 1985):

$$Y' = a + bQ' + cQ'^2 \tag{9}$$

where $Y' = \log Y$.

$Q' = \log Q$.

By retransformation it becomes:

$$Y = aQ^{b+c\log Q} \tag{10}$$

where b = linear coefficient.

c = curvature coefficient.

The main advantage of using the quadratic model is that the coefficient c can have a physically significant interpretation in terms of sediment supply (Parker and Troutman, 1989; Elsheikh, et al., 1991):

$c = 0$ -- unlimited sediment supply;

$c < 0$ -- limited sediment supply; and

$c > 0$ -- increasing sediment supply at larger streamflow. The linear model is a special case of the quadratic model ($c = 0$).

Period of basic data. SRCs are classified as instantaneous, daily, seasonal, annual, and flood or storm period curves. The sampling methods for instantaneous data can be time-based or discharge-based. The time-based method consists of simple random and systematic sampling. The systematic samples are collected in a fixed-time interval. Each simple random sample is collected by making equal probability selections (without replacement), which can be used when the population data are available. The discharge-based method consists of streamflow-proportional, selection at list-time, and group average sampling. The discharge-based methods can perform better when simulated than under field conditions. Probability sampling (though costly) is recommended for estimating suspended sediment yields, because the relationship between sampling and estimation is understood. Sampling methods have a large and systematic effect on the estimation of SRC parameters and estimation of suspended sediment yields (Glysson, 1987; Thomas, 1988).

Type of sediment. SRCs can be used to define the suspended sediment, bed material, or total sediment. They can be further partitioned according to size of particles (Glysson, 1987). As they are often used for suspended sediment, SRCs are usually referred to as suspended sediment rating curves.

Variables. Dependent variables can be sediment concentration or sediment discharge. The sediment concentration regression equation is:

$$C = aQ^b \tag{11}$$

The sediment discharge regression equation is:

$$Q_s = 86.4aQ^{b'} \tag{12}$$

where C = sediment concentration (mg/l).

Q = streamflow discharge (m^3/s).

Q_s = sediment discharge (usually m-ton/day).

b and b = parameters, theoretically, $b' = b + 1$.

86.4 = a unit conversion factor of Q (m^3/s) and C (mg/l) to Q_s (m-ton/day).

The levels of variance-explanation are higher for sediment discharge regression than sediment concentration regression, but the improvement is largely spurious because streamflow is common to both the dependent and independent variables (Walling, 1977; McBean and Al-Nassri, 1988). The concentration regression and sediment discharge regression are identical mathematically, hydrologically, and statistically (Gilroy, et al., 1990). Sediment concentration is used in this study.

SRCs usually have only one independent variable, streamflow discharge, but at times they can have other independent variables. Renard (1969) derived SRCs for ephemeral streams in southeastern Arizona, which had two independent variables, discharge and lapse time from the beginning of streamflow at the sampling station.

An alternative approach is to develop SRCs using the unit stream power as an independent variable. Bed material discharge is dependent on flow rate, while the wash load does not exhibit a clear functional relationship with flow rate (Graf, 1971). Yang (1973; 1988) found that unit stream power (VS) is the most important variable in the study of total sediment concentrations. VS is in m kg/kg/s. V is average flow velocity in m/s. S is energy or water surface slope and can be approximated by channel slope.

$$V = \frac{Q}{A} \tag{13}$$

where A = channel cross-sectional area (m^2).

Using unit stream power instead of streamflow, SRC for suspended bed material becomes:

$$C_b = a(VS)^b \tag{14}$$

or

$$\log C_b = \log a + b \log(VS) \tag{15}$$

where C_b = concentration of suspended bed material.

Walling and Teed (1971) used a pumping sampler on a small watershed of 0.26 km^2 in Exeter, UK. The plot of streamflow and sediment exhibited a considerable degree

of scatter ($r = 0.39$). To explain the scatter, an SRC was derived with the following four independent variables: time relation of sample to hydrograph peak, streamflow discharge, streamflow discharge preceding the hydrograph, and index of flood intensity.

Streamflow and sediment series can be out of phase (i.e., sediment series are lagged a few hours). If the data have a constant time interval (equally spaced), one can use the lagged sediment to improve SRCs (Gurnell and Fenn, 1984).

Methods for Developing SRCs

Methods for developing SRCs include visual fit, group average (Glysson, 1987), and least squares regression (Kmenta, 1986; Crawford, 1991). All methods should have two fundamental assumptions: (1) the model is appropriate for describing the data, and (2) the available data are representative of the population one is trying to describe (Daniel and Wood, 1980).

Visual fit, or hand-drawn graph fit, is visually drawing a single straight line, or connected, segmented straight line that appears to represent the best average or "fit." It is the simplest method.

The group average method uses the average (usually arithmetic mean) of all values of the dependent variable (sediment) for a small range of the independent variable (streamflow discharge). This method can remove the bias in the data caused by having more data points at one part than at another part of SRC (Glysson, 1987).

Least squares regression was used in this study. Different methods of least squares regressions produce different models: linear least squares (LLS) -- linear model, corrected linear least squares (CLLS) -- corrected linear model, and nonlinear least squares (NLS) -- nonlinear model. Basic assumptions for simple regression are: (1) the independent variable is nonstachastic, and (2) the random error ε_i has the properties of normality, zero mean, constant variance (homoskedasticity), $\mathrm{Var}(\varepsilon_i) = \sigma^2$, and nonautocorrelation, $\mathrm{Cov}(\varepsilon_i, \varepsilon_j) = 0$ $(i \neq j)$ (Kmenta, 1986).

Linear and corrected linear models. When the data are logarithmically transformed, the relationship between streamflow and sediment is usually linear and linear regression equation can be derived; it is then retransformed (antilogged). Estimates of parameters can be found algebraically (Crawford, 1991). Error term ε in the linear model is assumed multiplicative:

$$\log C = \log a + b \log Q + \varepsilon \tag{16}$$

or

$$C = a 10^{\varepsilon} Q^b \tag{17}$$

A linear model is the simplest model and is commonly used in developing SRCs.

The retransformation result is biased with respect to the original data (Ferguson, 1986). The transformation of the median of the original distribution becomes the median of the transformed distribution for any transformation that is a monotonic function. Since the residuals for the linear model are presumably normally distributed with mean 0, the

fitted straight line represents the median of the transformed dependent (response) variable, given the independent (explanatory) variable, as well as its mean. Consequently, the retransformed model represents the median value of the dependent variable given independent variable, rather than the mean (Miller, 1981). The bias of SRCs usually results in underestimation of the mean sediment data. The retransformation bias is greater when the number of measurements at low streamflow is relatively large and the variance of the data is great; sometimes it can reach 50%. If care is given to ensure that the curves are fitted through the points at the high end of the SRC and the variance of the residuals is small, errors in estimating sediment concentrations caused by this bias should be small (Jansson, 1985; Glysson, 1987).

To eliminate the retransformation bias the corrected linear model can be used. The residual (random error) of a model is:

$$\varepsilon = Y - \hat{Y} \tag{18}$$

for SRC:

$$\varepsilon_i = \log C_i - \log \hat{C}_i \tag{19}$$

where Y and $\hat{Y}$ = measured and calculated values of the dependent variable, respectively.

$\hat{C}_i$ = calculated sediment concentration (mg/l).

When ε_i is normally distributed with mean 0 and variance σ^2, $\varepsilon \sim N(0, \sigma^2)$, for common logarithmic regression, the following correction factor may be used (Jansson, 1985):

When ε_i is normally distributed with mean 0 and variance σ^2, $\varepsilon \sim N(0, \sigma^2)$, for common logarithmic regression, the following correction factor may be used (Jansson, 1985):

$$d = 10^{1.15\sigma^2} \tag{20}$$

where σ^2 = variance of ε.

Using the correction factor can eliminate the major portion of the bias of the estimator a (the curve is raised), but it does not correct the bias of b (the curve is not tilted) (Jansson, 1985). Without knowing the error distribution function or a reliable parametric form for it, a non-parametric correction factor proposed by Duan (1983) is better in calculating the correction factor (Koch and Smillie, 1986; Crawford, 1991):

$$d = \frac{1}{n}\sum 10^{\varepsilon_i} \tag{21}$$

Including the correction factor, the SRC becomes:

$$C = adQ^b \tag{22}$$

The corrected linear model can produce more precise estimates of SRC parameters and more accurate and precise estimates of mean suspended sediment discharge than the linear and nonlinear models (Crawford, 1991). The improvement by bias correction depends largely upon the sampling method and intensity as well as the set of discharges in the period being estimated (Thomas, 1988). The performance of the correction procedure is sensitive to the assumptions, particularly to that of normal distribution of error in estimating the untransformed scale expectation (Duan, 1983).

Nonlinear model. Using the original (untransformed) data, the nonlinear model can be used to directly derive the power function regression equation $C = aQ^b$. Estimates can be obtained iteratively but not algebraically. The error term in the nonlinear model is assumed additive:

$$C = aQ^b + \varepsilon \tag{23}$$

If there is a wide scatter of data points around the SRC, a nonlinear model differs considerably from a linear model. It is also assumed that the scatter plot (or residuals) of C against Q shows a similar degree of scatter at all streamflow discharges; this is not the case, i.e., the residuals typically are highly skewed and not identically distributed (Jansson, 1985; Ferguson, 1986; Crawford, 1991); this assumption is violated. If the residuals of a nonlinear model are independently, identically, and normally distributed, one can improve the nonlinear model by a weight of $1/\sigma_i^2$. σ_i^2 is the variance of the individual observation. It is called weighted nonlinear least squares (WNLS) (Wonnacott and Wonnacott, 1981). The difficulty is that the σ_i^2 values are rarely known (Crawford, 1991).

Runoff-frequency data can be obtained through the extrapolation of the annual-duration or partial-duration series of runoff; the use of double-mass comparisons of runoff or precipitation records, or both, for the subject watershed and adjacent areas; and an analysis of short-term rainfall-runoff relationships and a knowledge of the long-term rainfall pattern.

One problem of SRCs is that the residuals can be autocorrelated (serially correlated). Fenn et al. (1985) evaluated SRCs using data from a proglacial watershed of 4.8 km^2 in Switzerland, and found that residuals of an SRC from ordinary least squares regressions were autocorrelated for the original and lagged series at 2, 3, 4, 6, 12, and 24 hours. Their study indicated that there was more than one temporal scale of hysteresis, e.g., the variation in sediment supply over diurnal and seasonal scales. Autocorrelation could not be removed easily and remained a problem for the SRCs developed for different seasons and stages in their study (Fenn, et al., 1985).

Box-Jenkins transfer function models have been found to yield forecasts of sediment concentrations superior to the traditional SRC. However, a transfer function is difficult to estimate and requires a detailed series of equally spaced observations to allow its estimation (Gurnell and Fenn, 1984; Fenn, et al., 1985).

STUDY AREA

The study area was the Beaver Creek watersheds in the Colorado Plateau physiographic province within the Mogollon slope in north-central Arizona (Fig. 2). There are four vegetative types: semidesert, pinyon-Utah juniper, pinyon-alligator juniper, and ponderosa pine (Baker, 1982). The two pinyon-juniper types are commonly referred to as woodlands rather than forests because the trees are generally below sawtimber size.

Seven of the 20 experimental watersheds on Beaver Creek were studied. Watersheds 1, 2, and 3 were located in the pinyon-Utah juniper type (called pinyon-juniper type in this thesis); Watersheds 8, 12, 13, and 14 were located in the ponderosa pine type (Table 1).

Physiography

A high plateau, sloping mesas and breaks, steep canyons, and valleys characterize the topography on Beaver Creek. The bedrock underlying the area consists of igneous rocks of volcanic origin; below them are sedimentary rocks of Kaibab, Coconino, and Supai formations (Brown, et al., 1974).

The three pinyon-juniper watersheds have a range in average elevation of 1,597 to 1,691 m (Brown, 1971), and the four ponderosa pine watersheds have a range of 2,150 to 2,250 m (Baker, 1986a). The soils on the three pinyon-juniper watersheds are developed from volcanic materials, primarily basalts. The predominant soil is

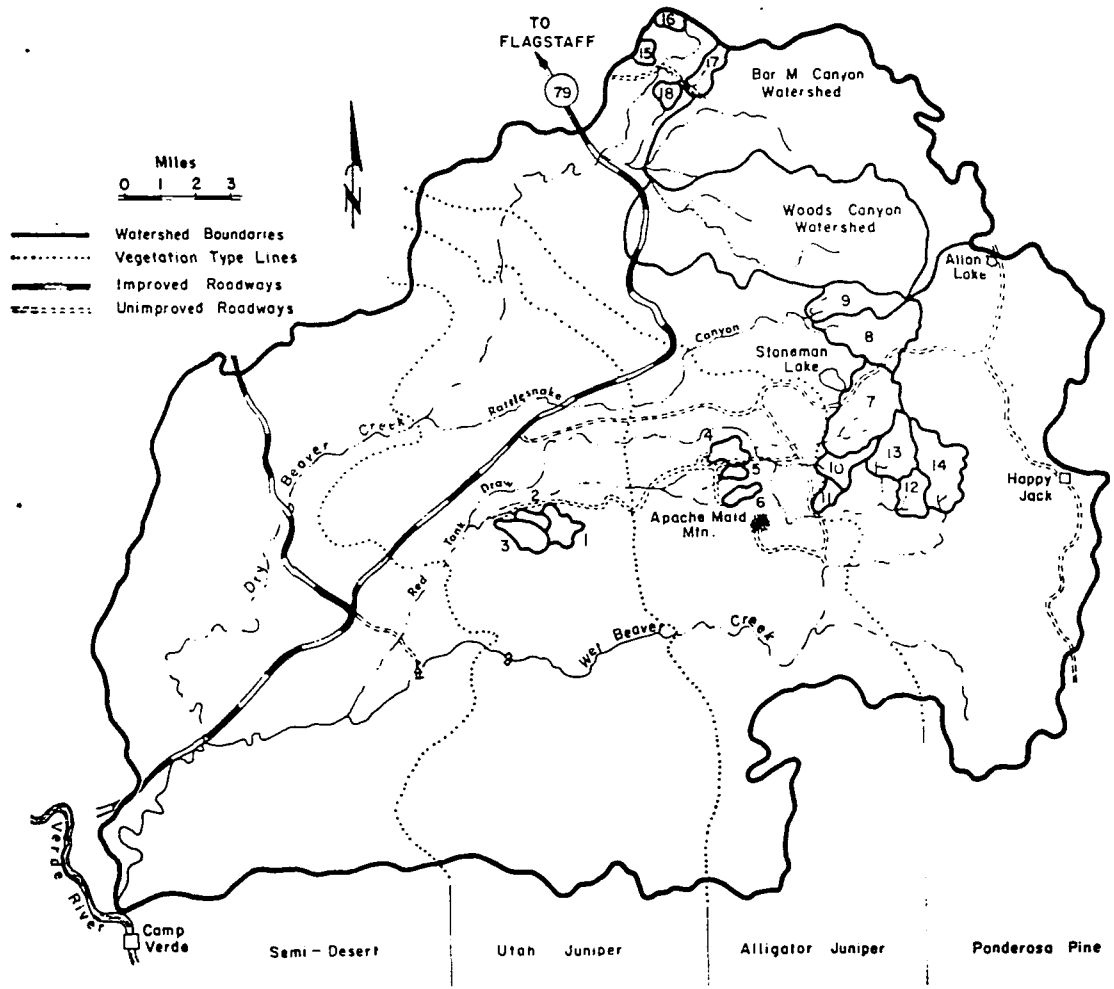


Figure 2. Illustration of the Beaver Creek Watersheds

Table 1. Physical characteristics and vegetative manipulations on the Beaver Creek watersheds

Vegetation	Ws	Area (ha)	Slope (%)	Elevation (m)	Vegetative Manipulations	Initial BA *	Residual BA	Overstory Removal (%)
Pinyon-Juniper	1	134	12	1691	1963, cabled, slash burned, regrowth	14	0	100
	2	51		1591	Control	12	12	0
	3	147	7	1573	1968, herbicide treated; removed and burned in 1976-77	13	2	83
Ponderosa Pine	8	730	10	2225	1974, lightly cut (silviculturally improved)	30	20	33
	12	184	7	2150	1966-67, clearcut, slash windrowed partial sprout control	24	0	100
	13	369		2195	Control	29	29	0
	14	546	11	2194	1970-71, stripcut and thinned	28	12	57

Ws = Watershed
* BA = Basal Area (m^2/s)

Springerville very stony clay. The typical profile is 112 cm deep, with a clay texture throughout (Clary, et al., 1974). The infiltration rates for this series range from 2.0 to 6.4 cm (0.8 to 2.5 inches) per hour, with permeability rates of less than 0.1 cm (0.05 inch). Water storage capacity for this soil series is over 46 cm (18 inches) (Williams and Anderson, 1967).

The soils on the ponderosa pine watersheds are developed on basalt and cinders parent materials, and are predominantly a Brolliar stony clay loam, and a Sponseller or a Siesta stony silt loam, respectively. The infiltration rates for the Brolliar series range from 2.0 to 6.4 cm (0.8 to 2.5 inches) per hour, with permeability rates ranging from 0.1 to 0.5 cm (0.05 to 0.2 inch). Water storage capacity for this soil series is between 15 and 46 cm (6 and 18 inches). The Siesta-Sponseller soil series has the same range of infiltration and permeability rates as the Brolliar soil series. Water storage capacity is over 46 cm (18 inches) (Williams and Anderson, 1967).

Productivity of Siesta-Sponseller and Brolliar is high and medium, respectively (Williams and Anderson, 1967). The soil depth is generally less than 1 m (Baker, 1986). Rainfall and snowmelt intensities greater than the range of permeability rates are common on Beaver Creek (U.S. Department of Commerce, 1967). Because of low permeability rates and small water storage capacity of soil, these watersheds have a high ratio of peak discharge to mean streamflow and often no flow between streamflow events (Baker, 1982, 1987).

Hydrologic Regime

There are two major precipitation seasons, winter (October to April) and summer (May to September). Widespread frontal storms and prolonged streamflows are common along the Mogollon Rim during the period from November through March. Over 60% of the annual precipitation falls in winter, with most of the remaining from July to September (Fig. 3, Table 2). The mean annual precipitation is 45.8 and 64.8 cm (18.03 and 25.50 inches) in pinyon-juniper and ponderosa pine types, respectively (Baker, 1982). Snowfall accounts for 18 and 37% of the annual precipitation for the two vegetative types, respectively. Typically, the snowpack is intermittent in the pinyon-juniper type and more-or-less continual in the ponderosa pine type. Nearly all summer precipitation occurs as thunderstorms (Baker, 1982).

Feth and Hem (1963) estimated that 98% of the precipitation on the Mogollon slope leaves the region as streamflow, evaporation, and transpiration, and only 2% reaches the sedimentary aquifers below the lava cover. Most of the annual water yield comes during the winter season. The ratio of mean annual water yield to winter precipitation (annual runoff efficiency) is 10 and 33% for the pinyon-juniper and ponderosa pine watersheds, respectively. Because of their soil types, vegetation density, and sparse litter cover, average annual peak discharge is higher on the pinyon-juniper watersheds (1.3 $m^3/s/km^2$) than the ponderosa pine watersheds (1.0 $m^3/s/km^2$). The median peak discharges on the pinyon-juniper and ponderosa pine watersheds are 0.4 and 0.5 $m^3/s/km^2$, respectively (Baker, 1982).

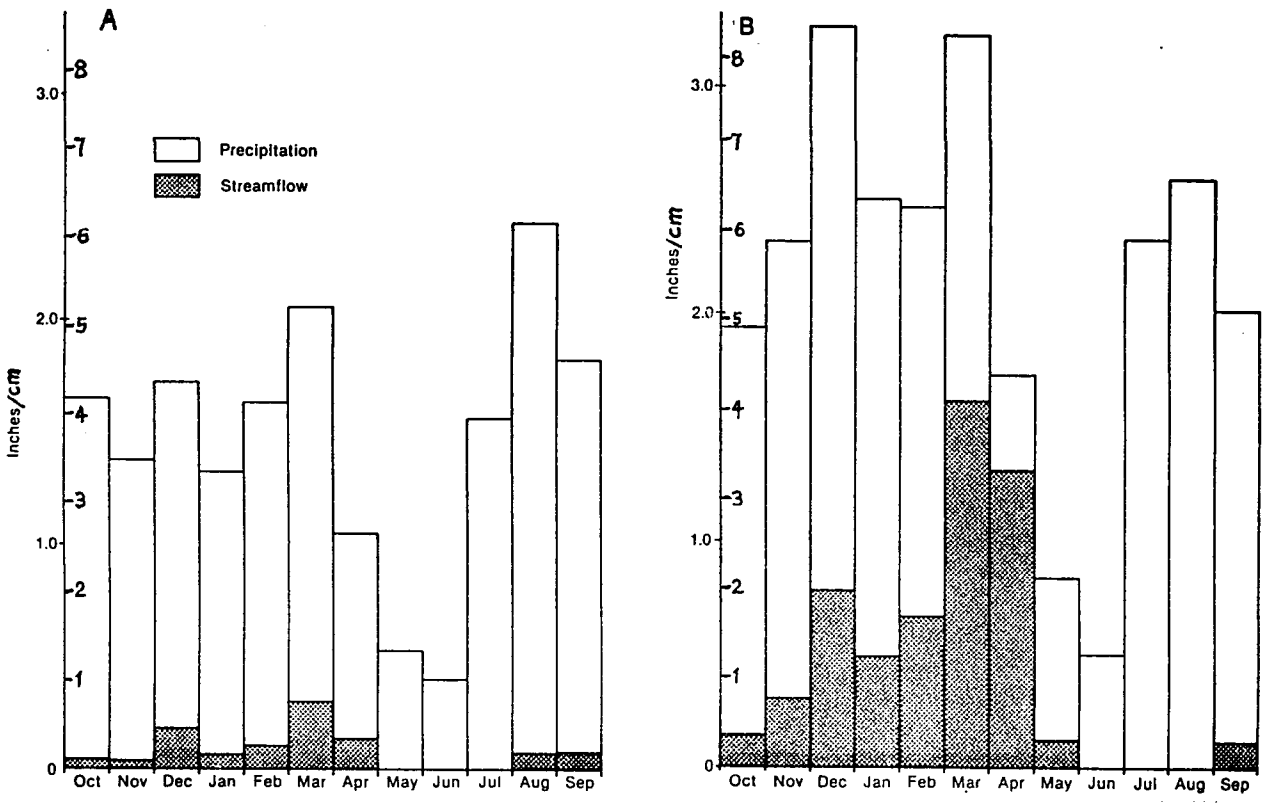


Figure 3. Distribution of monthly precipitation and streamflow on Beaver Creek in (A) pinyon-juniper and (B) ponderosa pine

Table 2. Precipitation and water yield

Unit: cm		Pinyon-Juniper * Mean	Pinyon-Juniper * Standard Deviation SD	Ponderosa Pine ** Mean	Ponderosa Pine ** Standard Deviation SD
Precipitation	Winter	28.0	11.4	43.1	17.3
	Summer	17.8	5.8	21.7	6.8
	Annual	45.8	10.5	64.8	16.6
Water Yield	Winter	2.3	3.8	13.8	12.6
	Summer	0.4	1.0	0.4	1.1
	Annual	2.7	3.7	14.1	12.4

* 49 station years of data
** 154 station years of data (Baker, 1982)

Winter streamflow is relatively low in October and November and increases in December. Watersheds in the two vegetative types generally reach their maximum water yield in March. Streamflow is essentially nonexistent in May (except where residual streamflow may continue from snowmelt), June, and July. Summer streamflow usually occurs only in August and September, and is less frequent on the ponderosa pine watersheds than the pinyon-juniper watersheds. Spring snowmelt is during February through April on the ponderosa pine watersheds and March through May on the pinyon-juniper watersheds (Baker, 1982).

Ninety-five percent of the streamflow is snowmelt (Haddad, 1990). Baker (1984) reported that more than 80% of the streamflow originates as direct flow on Watershed 3 (both before and after herbicide treatment).

Vegetative Treatments

Cabling and herbicide were the treatments on the pinyon-juniper watersheds, while thinning and clearcutting were the treatments on the ponderosa pine watersheds, both implemented to increase streamflow (Clary, et al., 1974; Brown, et al., 1974). Watershed 2 and 13 were the control.

Pinyon-Juniper Watersheds

The basal area of the pinyon-juniper averaged 14 m^2/ha (60 ft^2/ac) before the treatment. Under the overstory there were grasses, forbs, half-shrubs, and shrubs (Clary, et al., 1974). The principle grasses were blue grama, black grama, western wheatgrass, and foxtail. This area is used chiefly for summer grazing of livestock. The range condition of the untreated area was very poor because herbage yields were strongly depressed as the density of the pinyon-juniper stand increased (Clary, et al., 1974). The area was important as a big game habitat (Williams and Anderson, 1967).

Watershed 1. Cabling treatment was applied in 1963. The larger trees were uprooted by a heavy steel cable pulled between two bulldozers. Small trees missed by the cable were hand chopped, slash burned, and the area was seeded with a mixture of forage species. After the treatment the significant increases were in perennial grasses and in forbs and half-shrubs (Clary, et al., 1974).

Watershed 3. Herbicide treatment was applied in 1968, which consisted primarily of a helicopter application of 2 1/2 pounds of picloram and 5 pounds of 2, 4-D

per acre. The intent was to reduce transpiration losses by killing trees, to reduce evaporation losses by leaving the dead trees standing to reduce windspread and insolation, and to avoid the problem of overland flow being trapped in soil pits created when trees are uprooted. Eighty-three percent of the Utah juniper were killed by herbicide treatment on the entire watershed (Clary, et al., 1974). Shrub live oak and pinyon were damaged by the herbicide but showed marked recovery after 2 or 3 years. Cliffrose was moderately damaged but recovered quickly. Side-oats grama and other established perennial grasses were undamaged (Baker, 1984). The treatment resulted in significant increases in production of understory plants (Clary, et al., 1974). Numerous annual forbs and grasses invaded after the treatment, but perennial grasses were more apparent for four years (Baker, 1984).

Watershed 2. This watershed served as the control for the treatment-experiments in the pinyon-juniper type. The basal area was 13 m^2/ha (57 ft^2/ac) (Clary, et al., 1974).

Ponderosa Pine Watersheds

The ponderosa pine forest is composed of a mixture of uneven-aged ponderosa pine, Gambel oak, and alligator juniper (Brown, et al., 1974). The ground was covered with either grass or an accumulation of pine needles. The ground cover density of vegetation for the experimental watersheds was 64-76% (Williams and Anderson, 1967).

Perennial grasses included bottlebrush squirreltail, mutton bluegrass, blue grama, and black dropseed (Brown, et al., 1974).

Watershed 8. Silvicultural improvements were applied in 1974 (Ward and Baker, 1984). Ponderosa pine trees ≤ 25 cm diameter breast high (dbh) were thinned to an average basal area of 14 m^2/ha; trees ≥ 25 cm dbh and ≤ 56 dbh were thinned to a basal area of 16 m^2/ha; larger trees were cut into a shelterwood system (Ffolliott, et al., 1991). The overstory basal area was reduced by 33%, from 30 to 20 m^2/ha (Baker, 1986a). Logging roads were located to minimize erosion potential and visual impact. Grass seed was sown for erosion control on closed roadways, log landings, skid trails, and steep slopes where there had been major soil disturbance. Slash from dense stands, fuel breaks, roadside areas, and from around the private land, was piled and burned, or lopped and scattered in the more open stands. Some slash on the watershed was chipped and scattered.

Watershed 12. Watershed 12 was clearcut in 1966-1967. All merchantable poles and sawtimber were removed and the remaining nonmerchantable timber felled. In order to trap and retain snow, reduce evapotransporation losses, and increase surface drainage efficiency, all slash and debris were machine-windrowed to the orientations (providing maximum shade or perpendicular to the prevailing wind, and sub-perpendicular to the slope). The windrows were at least 1.5 m high and spaced approximately 30 m apart (Baker, 1986a). Oak sprouts were partially controlled with chemical sprays (Brown, et al., 1974). The windrows were removed by burning in 1977 (Baker, 1986a).

Watershed 14. Watershed 14 was stripcut in 1970-1971 (Brown, et al., 1974). One-third of the area was cleared in irregular strips averaging 20 m wide; trees in leave areas were thinned to a basal area of 14 m^2/ha (Ffolliott and Gottfried, 1991). The overall treatment resulted in a basal area reduction of 57%, from 28 to 12 m^2/ha (Baker, 1986a). Slash was piled and burned. Gambel oak was retained for mast and browse (Ffolliott and Gottfried, 1991).

Watershed 13. This watershed was used as a control.

METHODOLOGY

Data Collection

Simultaneous measurements of streamflow discharge and sediment concentrations were conducted. Measurements on the watersheds used in this study were made in 1975-1982 (Watershed 14 in 1974-1982), 1-12 years after the initial treatments of the treated watersheds.

Streamflow was measured in concrete trapezoidal flumes (Baker, 1986b). PS-69 pumping samplers were used to collect sediment concentrations at predetermined intervals (Ward and Baker, 1984). A PS-69 sampler has a capacity for 72 1-liter sample containers (USGS, 1977). The time interval of the sediment measurements ranged from 5 minutes to 24 hours and the minimum of 1 hour was used to select data; measurements within 1 hour were ignored. Averages of sediment measurements were not used because they do not indicate the variation of individual data points (Davis, 1994).

Analytical Procedures

Graphical Analysis

Graphical analysis was conducted before mathematically developing SRCs. The data were plotted on a log-log scale and the following questions were answered: (1) Should the relationship be one or more straight lines or a curve? (2) Do the data cover the entire range of water discharge? (3) Do the data cover both the wet and dry periods,

winter and summer seasons, and all phases of the hydrograph? (4) Are there any data from atypical years or streamflow-sediment events (outliers) which could incorrectly bias the relation? (5) Are the data representative of a number of events or a single event, especially at the upper end of SRC? This preliminary analysis revealed significant relations and avoided misinterpretation (Glysson, 1987).

Mathematical Derivation of SRCs

SRC parameters were estimated by linear least squares regressions of the model:

$$\log C = \log a + b \log Q \tag{24}$$

which was transformed from the original model:

$$C = aQ^b \tag{25}$$

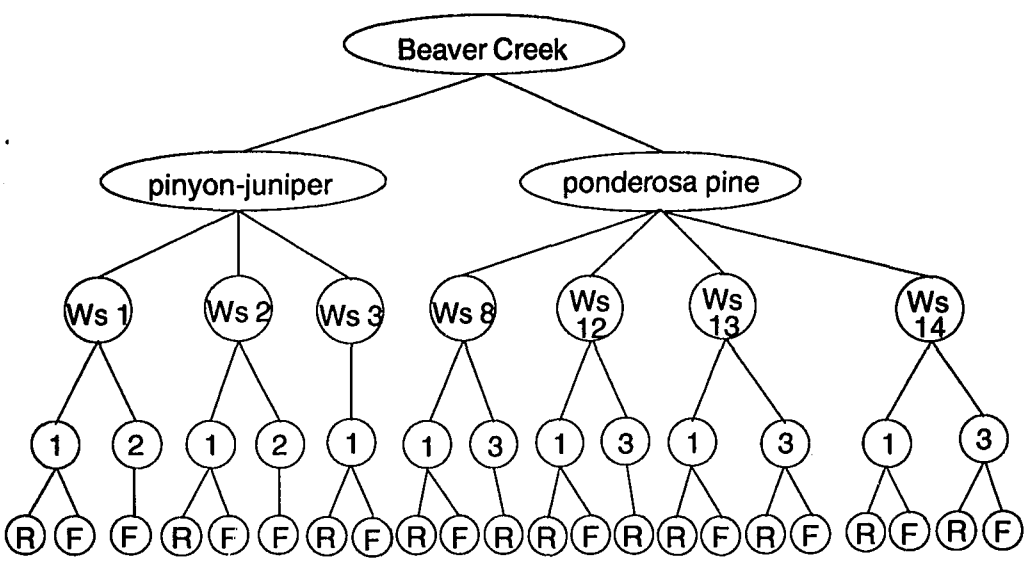
Here Q is in m^3/s. For Q' in cfs:

$$C = a(0.0283Q')^b = a_1 Q'^b \tag{26}$$

where $a_1 = a(0.0283^b)$.

The principles and assumptions described earlier regarding least squares regression apply to the transformed model (Eq. 24), not the original model (Eq. 25) (Haan, 1977).

SRCs were derived for each watershed; when data were available, SRCs were derived for each type of streamflow-generating events on a watershed and for each hydrograph stage in a type of events (Fig. 4).



1, 2, and 3 = Event types; R and F = Rising and falling stage, respectively

Figure 4. Tree of the data structure

Examination of Regression Equations

Analysis of variance (ANOVA) was used to test the significance of regressions and to compare different models. The significance of regressions was tested by F statistic $F_{\alpha,1,n-2}$. All hypothesis tests in this study were conducted at significance level $\alpha = 0.05$. For the null hypothesis H_0: $b = 0$, if the observed F ratio $F = MSR/MSE > F_{\alpha,1,n-2}$, H_0 was rejected. MSR is mean squares for regression, MSR = SSR. SSR is sum squares for regression:

$$SSR = \sum (\hat{Y}_i - \overline{Y})^2 \tag{27}$$

MSE is residual mean squares (variance of residuals, s^2), MSE = SSE/(n - 2). SSE is residual (error) sum of squares:

$$SSE = \sum (Y_i - \hat{Y}_i)^2 \tag{28}$$

For prediction, the observed F ratio should be at least 4 or 5 times $F_{\alpha,1,n-2}$ (Ryan, 1990). The F statistic was $F_{\alpha,2,n-2}$. t statistic was used to test H_0: $c = 0$ (Haan, 1977). If $t > t_{1-\frac{\alpha}{2},n-2}$, H_0 was rejected.

The following statistics were calculated to compare different models: standard error (SE), mean error, and residual (ε).

$$SE = MSE^{0.5} \tag{29}$$

$$E\,(\%) = \left(\frac{\hat{Y}}{Y} - 1\right) * 100 \tag{30}$$

where E = error.

Two measures of association were also used to describe the degree of descriptive power between dependent and independent variables, coefficient of determination (r^2) and correlation coefficient (r, square root of r^2) (Neter, et al., 1988). r^2 was used as a measure of the ability of the regression equation to explain variations in the dependent variable (percentage variation explained); r was used to analyze the improvement of SRCs through partitioning data.

$$r^2 = \frac{\sum (\hat{Y}_i - \bar{Y})^2}{\sum (Y_i - \bar{Y})^2} \tag{31}$$

The numerator is the sum of squares due to regression and the denominator is the sum of squares corrected for mean. An adjusted coefficient of determination (r_a^2) adjusts the value of r^2 to take into account the fact that a regression model always fits the specific data (on which it was developed) better than the population (Norusis, 1985):

$$r_a^2 = r^2 - \frac{p(1-r^2)}{n-p-1} \tag{32}$$

where p = number of independent variables, $p = 1$.

n = sample size.

Test for Significance of Differences Between SRCs

Chow test (Kmenta, 1986) was used to test the significance of differences between SRCs. For any two SRCs:

$$\log C_i = \log a_1 + b_1 \log Q_i + \varepsilon_i \quad (i = 1, ..., n) \tag{33}$$

$$\log C_i = \log a_2 + b_2 \log Q_i + \varepsilon_i \quad (i = n+1, ..., n+m) \tag{34}$$

H_0: $a_1 = a_2$ and $b_1 = b_2$

$$\frac{(SSE_R - SSE_1 - SSE_2)/K}{(SSE_1 + SSE_2)/(n+m-2K)} \sim F_{K,n+m-2K} \tag{35}$$

where SSE_R = restricted error sum of squares (i.e., error sum of squares when the hypothesis is imposed).

SSE_1 and SSE_2 = error sum of squares for SRC 1 and 2, respectively.

K = number of restricted coefficients, $K = 2$.

n and m = sizes of data used for developing and testing SRC 1 and 2, respectively.

Confidence and Prediction Intervals

X_h denoted the level of X for which one wishes to estimate the mean response. X_h might be a value that occurred in the sample, or it might be some other value of the independent variable within the scope of the model. The mean response when $X = X_h$ was denoted by $E(Y_h)$. The point estimator $\hat{Y}_h$ of $E(Y_h)$ was:

$$\hat{Y}_h = a + bX_h \tag{36}$$

The estimated standard deviation of $\hat{Y}_h$ was $s(\hat{Y}_h)$, the square root of $s^2(\hat{Y}_h)$:

$$s^2(\hat{Y}_h) = MSE\left[\frac{1}{n} + \frac{(X_h - \bar{X})^2}{\sum (X_h - \bar{X})^2}\right] \tag{37}$$

$\frac{\hat{Y}_h - E(Y_h)}{s(\hat{Y}_h)}$ was distributed as $t(n\text{-}2)$. The 1-α confidence intervals for $E(Y_h)$ (Neter, et al., 1985) were:

$$\hat{Y}_h \pm t(1-\frac{\alpha}{2}, n-2)s(\hat{Y}_h) \quad (38)$$

$X_{h(new)}$ denoted the new observation,

$$s^2(\hat{Y}_{h(new)}) = MSE\left[1+\frac{1}{n}+\frac{(X_h-\bar{X})^2}{\sum(X_h-\bar{X})^2}\right] \quad (39)$$

The 1-α confidence intervals for $E(Y_{h(new)})$ were:

$$\hat{Y}_h \pm t(1-\frac{\alpha}{2}, n-2)s(\hat{Y}_{h(new)}) \quad (40)$$

Confidence intervals were computed for $\alpha = 0.05$.

Partitioning of Data

The effects of vegetative manipulations on sediment concentrations were analyzed at three levels: watershed, event, and stage (Fig. 4). According to the streamflow generating mechanism, each data set at the watershed level was partitioned into three types of events:

Event 1 -- snowmelt-runoff (February to May).

Event 2 -- convectional rainfall (June to September).

Event 3 -- frontal rainfall (October to January).

Streamflow from event 1, which contributes most of the water yield on Beaver Creek, has a duration of several days or weeks, with a slow response time to peak streamflow. Streamflow from event 2 has a duration of hours or a few days, with a rapid response time to peak streamflow. Streamflow from event 3 has a duration of several

days, with a moderate response time to peak streamflow (Lopes and Ffolliott, 1993). Sample sizes by watershed for the respective events and stages are shown in Tables 3 and 4. Statistics of streamflow and sediment for all the data sets are listed in Appendix B.

Each data set at event level was also partitioned into rising and falling stages of the hydrograph to analyze the effect of hysteresis. The partitioning method was similar to that used by Hansen (1966), Walling (1977), and Lopes and Ffolliott (1993). When streamflow increased more than a threshold discharge within a specified time period the hydrograph was considered as being at a rising stage; otherwise, it was considered as being at a falling stage, although the term 'falling stage and steady stage" might be more appropriate. The threshold discharge was employed to ignore small changes in streamflow. Threshold values of 0.5 and 5.0 m^3/s for the pinyon-juniper and ponderosa pine watersheds, respectively, were selected through graphical analysis of the hydrographs. The time period was 24 hours, except for snowmelt-runoff events on the pinyon-juniper watersheds which had a duration of 5 days.

Table 3. SRC parameters and statistics (pinyon-juniper)

Ws	Event Type	Stg	*n*	*a*	95% Confidence Intervals		*b*	95% Confidence Intervals		Standard Error SE	r_a^2	F Statistic	Signif.
1	-	-	525	7.362	5.297	10.257	0.233	0.143	0.324	7.03	0.05	39.33	**
	1	-	429	6.982	4.831	10.069	0.216	0.114	0.318	7.37	0.04	17.26	**
		R	93	66.222	26.122	105.925	0.779	0.632	0.956	9.79	0.54	111.01	**
		F	333	1.858			-0.112				0.01	3.86	-
	2	-	90	6.668	3.013	14.757	0.231	0.025	0.438	4.17	0.04	4.94	**
		R	20	38.905	10.116	149.624	0.529	0.190	0.868	2.92	0.34	10.77	**
		F	70	4.315			0.161				0.01	2.04	-
2	-	-	519	5.129	3.664	7.161	0.193	0.112	0.274	2.98	0.04	22.01	**
	1	-	448	4.335	3.013	6.237	0.168	0.081	0.256	3.13	0.03	14.24	**
		R	153	13.772	6.730	28.119	0.438	0.253	0.625	4.23	0.12	21.82	**
		F	288	3.006			0.088				0.01	3.49	-
	2	-	65	14.125	6.124	32.509	0.363	0.157	0.568	2.74	0.15	12.37	**
		R	12	16.672	10.789	25.763	0.172	0.073	0.270	1.22	0.51	15.16	**
		F	53	29.923			0.613				0.46	45.88	**
3	-	-	611	8.091	5.916	11.066	0.245	0.168	0.321	4.67	0.06	25.76	**
	1	-	572	8.147	5.984	11.092	0.244	0.168	0.320	4.95	0.06	40.13	**
		R	203	29.174	17.179	49.431	0.547	0.408	0.685	6.66	0.23	60.46	**
		F	362	4.457	3.097	6.412	0.120	0.034	0.206	2.31	0.02	7.48	**
	2	-	33	15.136			0.500				0.01	1.23	-
		R	9	0.001			-2.034				0.02	1.18	-
		F	23	13.614			0.518				0.02	1.45	-

F statistic: Equation significant at $\alpha = 0.05$

Signif.: Regression significant (**) or insignificant (-) at $\alpha = 0.05$

Table 4. SRC parameters and statistics (ponderosa pine)

Ws	Event Type	Stg	*n*	*a*	95% Confidence Intervals		*b*	95% Confidence Intervals		Standard Error SE	r^2_a	F Statistic	Signif.
8	-	-	854	14.394	12.369	16.724	0.560	0.507	0.612	19.61	0.34	437.63	**
	1	-	828	14.396	12.380	16.777	0.577	0.525	0.630	19.52	0.36	462.29	**
		R	250	16.101	11.382	22.814	0.853	0.749	0.957	27.53	0.51	261.36	**
		F	327	13.385	10.573	16.912	0.509	0.429	0.588	11.03	0.32	157.07	**
	3	-	26	12.554			0.100				-0.03	0.25	-
		R	9	23.936			0.690				0.22	3.20	-
		F	8	3.908			-0.572				0.12	1.94	-
12	-	-	353	154.579	121.667	196.413	1.042	0.947	1.137	125.97	0.57	468.54	**
	1	-	326	155.234	120.370	200.224	1.066	0.964	1.167	125.39	0.57	426.87	**
		R	148	170.847	114.559	254.700	1.027	0.877	1.177	169.38	0.55	182.82	**
		F	131	141.415	99.093	201.393	1.198	1.058	1.399	64.91	0.69	282.32	**
	3	-	26	162.577	83.813	315.726	0.865	0.634	1.097	135.65	0.70	59.38	**
		R	12	175.942	46.664	663.722	0.880	0.693	1.267	182.39	0.69	25.69	**
		F	14	127.938	14.280	14.280	0.746	0.287	1.205	98.82	0.47	12.55	**
13	-	-	204	28.679	21.804	37.717	0.677	0.579	0.776	61.40	0.47	183.40	**
	1	-	179	26.272	19.909	34.678	0.665	0.560	0.770	64.44	0.47	156.44	**
		R	44	39.853	15.288	103.837	1.030	0.745	1.315	94.37	0.55	53.35	**
		F	71	21.670	12.754	36.782	0.608	0.425	0.790	56.86	0.38	44.01	**
	3	-	25	44.386			0.301				0.11	3.82	-
		R	8	76.552	13.355	439.197	0.537	0.038	1.036	50.60	0.46	6.94	**
		F	12	36.196	10.800	121.456	0.938	0.512	1.164	24.14	0.74	32.77	**
14	-	-	473	56.491	44.945	70.906	0.974	0.886	1.062	73.24	0.50	475.87	**
	1	-	432	54.590	43.335	68.681	1.008	0.919	1.097	74.94	0.53	494.69	**
		R	140	74.788	75.944	112.071	1.156	1.019	1.294	97.63	0.66	276.26	**
		F	154	44.905	30.817	65.431	0.879	0.740	1.018	46.72	0.50	156.45	**
	3	-	41	80.902	42.763	153.134	0.578	0.341	0.815	50.12	0.37	24.31	**
		R	20	112.158	54.425	231.101	0.495	0.245	0.746	55.15	0.46	17.21	**
		F	9	53.151			0.560				0.30	4.43	-

RESULTS AND DISCUSSION

Since Watershed 12 had sufficient data for the entire range of streamflow and sediment, it was used to test different models. Watersheds 8 and 13 were also used to test some models because Watershed 8 had the largest sample size and Watershed 13 represented the untreated condition.

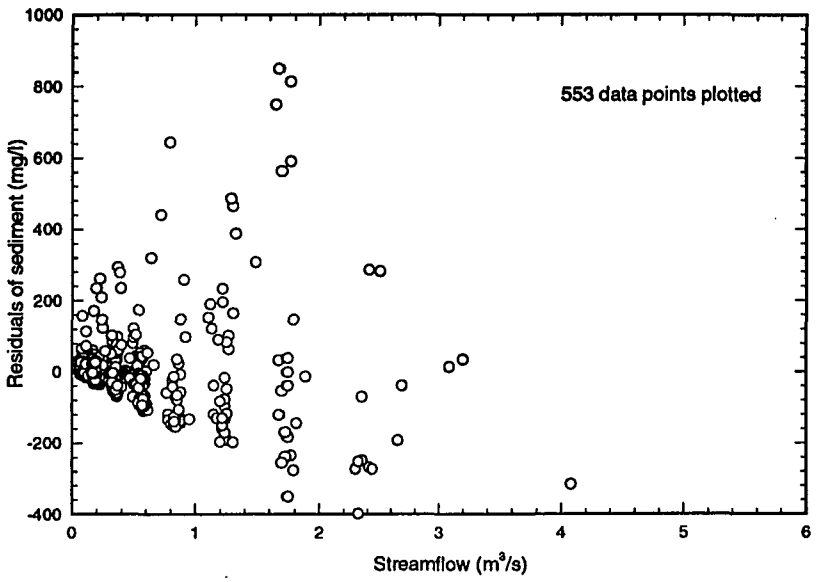
Comparison of Different SRC Models

Linear and Nonlinear Models

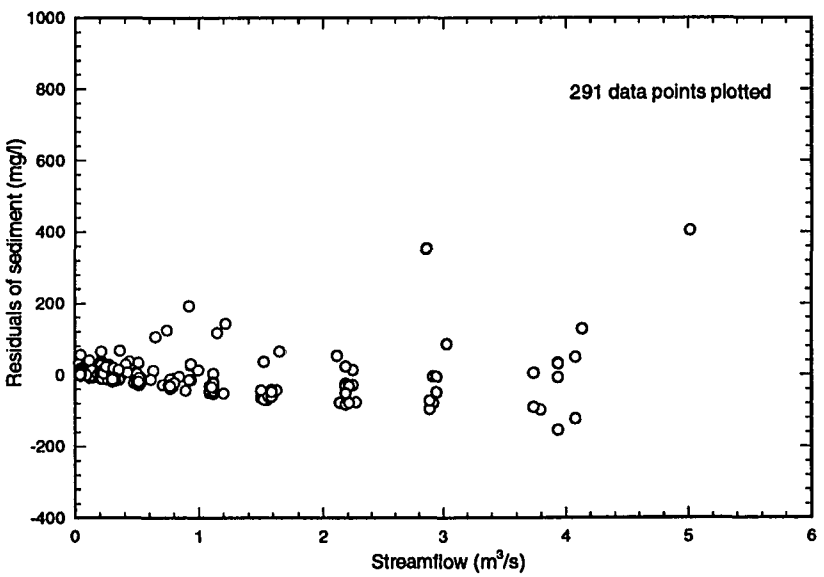
When the nonlinear model was tested in this study, the residuals of the regression equation did not exhibit a constant variance. The higher the streamflow, the larger the variance, as illustrated in Fig. 5. The variance of residuals was not normally distributed. The basic assumptions of normality and constant variance were violated in the nonlinear model. The linear model met the assumptions of normality and constant variance (Fig. 6). Parameters and statistics of the linear model are listed in Tables 3 and 4.

Linear, Corrected Linear, and Quadratic Models

A quadratic model was tested using data from Watershed 12. Parameters and statistics for this test are listed in Table 5. The quadratic model had a higher value of r_a^2 than the linear model. The quadratic model simulated streamflow-sediment relationships better than the linear model at high streamflows that contributed much



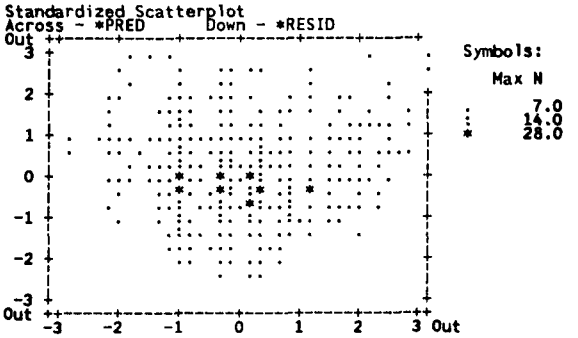
A. Watershed 12



B. Watershed 13

Figure 5. Residuals of the nonlinear model for Watersheds 12 and 13

	Min	Max	Mean	Std Dev	N
*PRED	.3362	1.6490	.9554	.2140	854
*RESID	-.7250	.9265	.0000	.2986	854
*ZPRED	-2.8931	3.2408	.0000	1.0000	854
*ZRESID	-2.4263	3.1004	.0000	.9994	854




```
Histogram - Standardized Residual
 N Exp N      (* = 1 Cases,    . : = Normal Curve)
 1   .94   Out :
 3   .48  3.00 ***
 2   .69  2.88 :*
 4   .97  2.75 :***
 2  1.36  2.63 :*
 4  1.88  2.50 *:**
 3  2.55  2.38 **:
 6  3.40  2.25 **:***
 8  4.46  2.13 ***:****
 9  5.77  2.00 *****:***
 8  7.35  1.88 ******:*
 6  9.22  1.75 ******  .
13 11.39  1.63 **********:**
 8 13.84  1.50 ********      .
 8 16.56  1.38 ********        .
17 19.50  1.25 *****************  .
18 22.62  1.13 ******************     .
11 25.83  1.00 ***********              .
35 29.04   .88 ****************************:******
26 32.14   .75 **************************          .
32 35.02   .63 ********************************       .
24 37.56   .50 ************************                 .
33 39.67   .38 *********************************          .
41 41.25   .25 ****************************************:
44 42.23   .13 ****************************************:**
49 42.56   .00 ****************************************:******
46 42.23  -.13 ****************************************:****
46 41.25  -.25 ***************************************:*****
56 39.67  -.38 ****************************************:****************
46 37.56  -.50 ***********************************:********
36 35.02  -.63 *********************************:*
41 32.14  -.75 ******************************:*********
40 29.04  -.88 ****************************:***********
26 25.83 -1.00 *************************:
18 22.62 -1.13 ******************     .
21 19.50 -1.25 ********************:*
12 16.56 -1.38 ************  .
12 13.84 -1.50 ************ .
10 11.39 -1.63 **********.
 4  9.22 -1.75 ****    .
 9  7.35 -1.88 ******:**
 7  5.77 -2.00 *****:*
 0  4.46 -2.13   .
 5  3.40 -2.25 **:**
 4  2.55 -2.38 **:*
 0  1.88 -2.50  .
 0  1.36 -2.63 .
 0   .97 -2.75 .
 0   .69 -2.88 .
 0   .48 -3.00
 0   .94   Out .
```

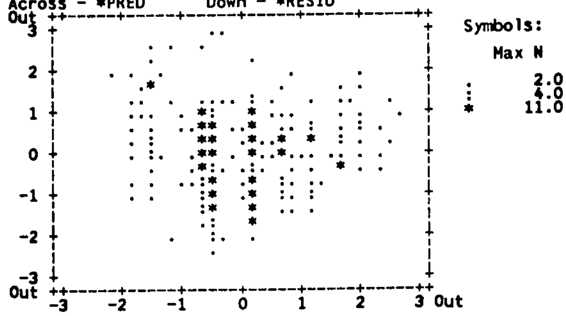
A. Watershed 8

Figure 6. Residual analysis for Watersheds 8 and 12

Residuals Statistics:

	Min	Max	Mean	Std Dev	N
*PRED	.8108	2.7156	1.6518	.3875	353
*RESID	-.7658	.9828	.0000	.3354	353
*ZPRED	-2.1705	2.7457	.0000	1.0000	353
*ZRESID	-2.2804	2.9264	.0000	.9986	353

Total Cases = 353
Standardized Scatterplot
Across - *PRED Down - *RESID




```
Histogram - Standardized Residual
 N Exp N        (* = 1 Cases,    . : = Normal Curve)
 0   .39   Out
 0   .20  3.00
 2   .28  2.88 **
 2   .40  2.75 **
 0   .56  2.63 .
 2   .78  2.50 :*
 1  1.05  2.38 :
 0  1.40  2.25 .
 3  1.85  2.13 *:*
 1  2.39  2.00 *.
 2  3.04  1.88 **.
 6  3.81  1.75 ***:**
 5  4.71  1.63 ****:
 3  5.72  1.50 ***  .
 5  6.84  1.38 *****  .
10  8.06  1.25 *******:**
 8  9.35  1.13 ********.
12 10.68  1.00 **********:*
11 12.00   .88 ***********.
 9 13.28   .75 *********    .
14 14.47   .63 *************:
18 15.53   .50 ***************:**
16 16.40   .38 ***************:
18 17.05   .25 ****************:*
28 17.46   .13 ****************:***********
14 17.59   .00 **************    .
15 17.46  -.13 ***************  .
11 17.05  -.25 ***********      .
12 16.40  -.38 ************    .
15 15.53  -.50 ***************.
14 14.47  -.63 *************:
18 13.28  -.75 ************:*****
13 12.00  -.88 ***********:*
 9 10.68 -1.00 *********  .
12  9.35 -1.13 ********:***
11  8.06 -1.25 *******:***
 9  6.84 -1.38 ******:**
 7  5.72 -1.50 *****:*
 2  4.71 -1.63 **   .
 4  3.81 -1.75 ***:
 5  3.04 -1.88 **:**
 5  2.39 -2.00 *:***
 0  1.85 -2.13  .
 1  1.40 -2.25 :
 0  1.05 -2.38 .
 0   .78 -2.50 .
 0   .56 -2.63 .
 0   .40 -2.75
 0   .28 -2.88
 0   .20 -3.00
 0   .39   Out
```

B. Watershed 12

Figure 6. Residual analysis for Watersheds 8 and 12 - continued

Table 5. Parameters and statistics of the quadratic model

Ws	Event type	Stg	*n*	*a*	95% Confidence Intervals		*b*	95% Confidence Intervals		*c*	95% Confidence Intervals	
12	-	-	353	325.73	41.67	2561	1.884	1.455	2.314	0.560	0.372	0.748
	1	-	326	299.93	32.95	2724	1.877	1.415	2.339	0.587	0.381	0.793
		R	148	227.56	9.58	5426	1.649	0.996	2.303	0.662	0.382	0.942
		F	131	290.28	11.05	7643	2.050	1.363	2.737	0.558	0.248	0.868
	3	-	26	149.94	0.85	26466	1.364	0.295	2.433	0.626	0.198	1.053
		R	12	263.48	0.02	3111943	1.548	-0.346	3.441	0.548	-0.183	1.280
		F	14	57.19	0.01	318185	1.029	-0.772	2.829	0.778	0.030	1.526

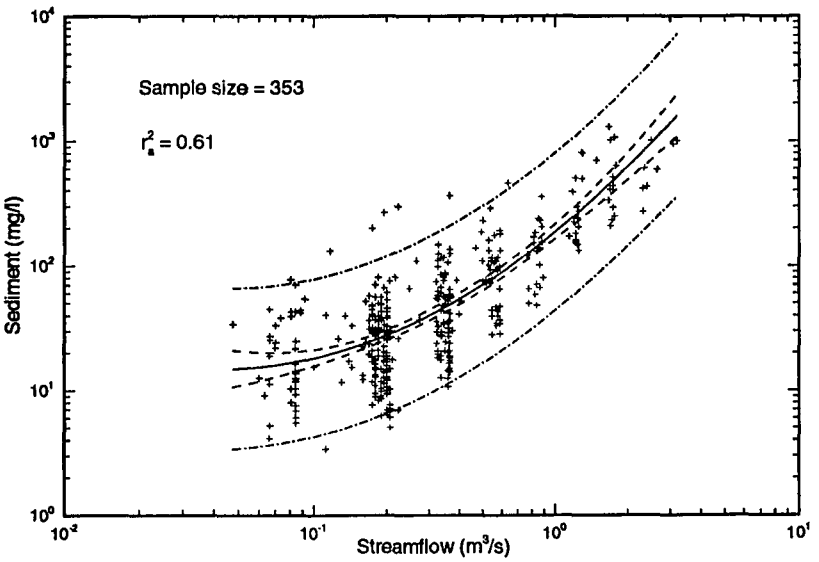
Ws	Event Type	Stg	r_a^2	t Statistic	F Statistic	SSE	SE	Mean E (%)	Mean Residual
12	-	-	0.61	5.86	185.44	4993832	119	38	5.5
	1	-	0.61	5.61	168.33	4703941	120	31	12.1
		R	0.60	4.67	76.40	4143352	168	16	53.0
		F	0.71	3.57	109.98	546737	65	25	3.4
	3	-	0.79	3.04	33.41	582082	156	-8	66.2
		R	0.72	1.73*	12.18	115833	108	15	6.0
		F	0.55	2.32	7.48	265686	149	-12	46.8

t Statistic: Significant at $a = 0.05$ except *

F Statistic: Equation significant at $a = 0.05$

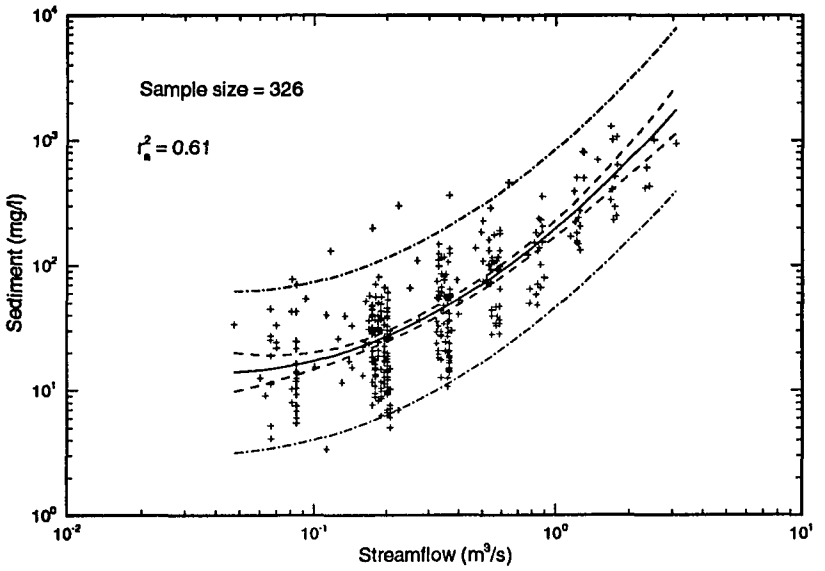
sediment yield (Figs. 7 and 8). At the three levels of analysis, *c*'s were larger than 0, possibly indicating an unlimited supply of sediment.

Linear least squares regressions can result in some bias when the linear model is retransformed to power function (Walling, 1977). The bias commonly occurs when sample sizes are small or sediment discharge is estimated during high streamflow conditions (Cohn, et al., 1989). The bias is usually represented by an underestimation of sediment concentrations. A correction factor (Duan, 1983; Jansson, 1985) can be included to eliminate some of the bias, which is called corrected linear model. The corrected linear model was tested on the ponderosa pine watersheds (see Appendix B). There was bias when the quadratic model was retransformed, but no method is available to calculate s correction factor for the quadratic model. As there were fewer data points at high streamflow, the corrected linear model had better results than the quadratic model. The retransformed models were tested with measured data. The corrected linear model had the smallest mean residuals (Table 6). For the SRCs of Watershed 12 at watershed, event, and stage levels, the mean residuals ranged from 16.0 to 44.6 for the linear model, 3.4 to 66.2 for the quadratic model, 0.6 to 15.1 for corrected linear model 1, and 2.1 to 13.4 for corrected linear model 2 (nonparametric model). As some error distributions of SRCs were not normal, the nonparametric model is recommended for SRCs. The linear model was used as the basic method in this thesis.

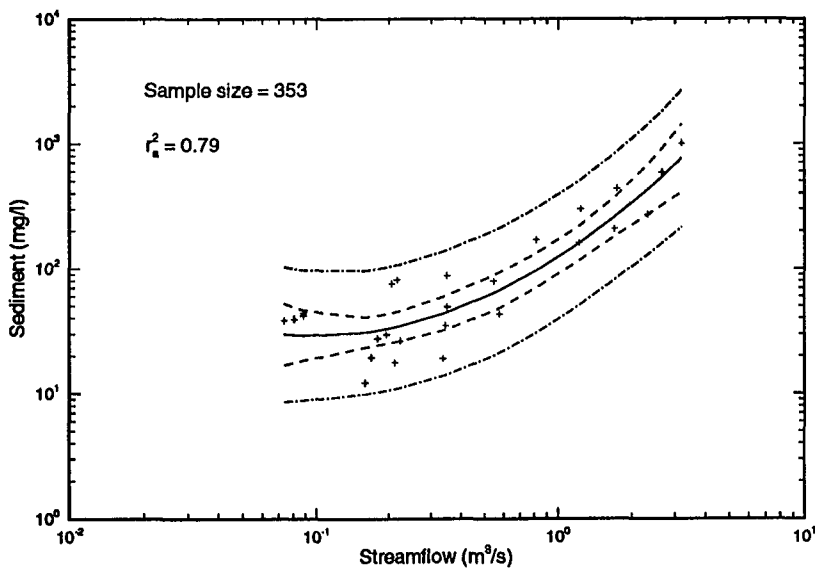


A. Watershed level

Figure 7. Quadratic models and 95% confidence and prediction intervals for Watershed 12

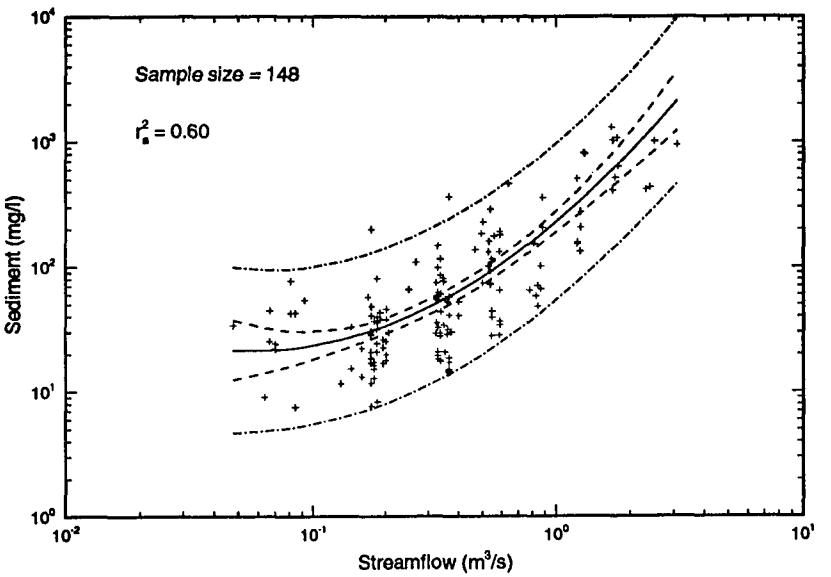


B. Event 1

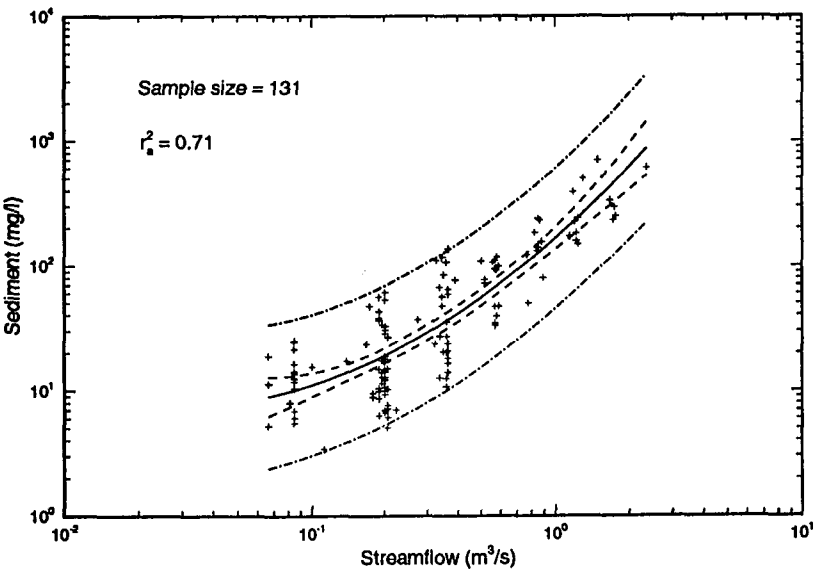


C. Event 3

Figure 7. Quadratic model and 95% confidence and prediction intervals for Watershed 12 - continued

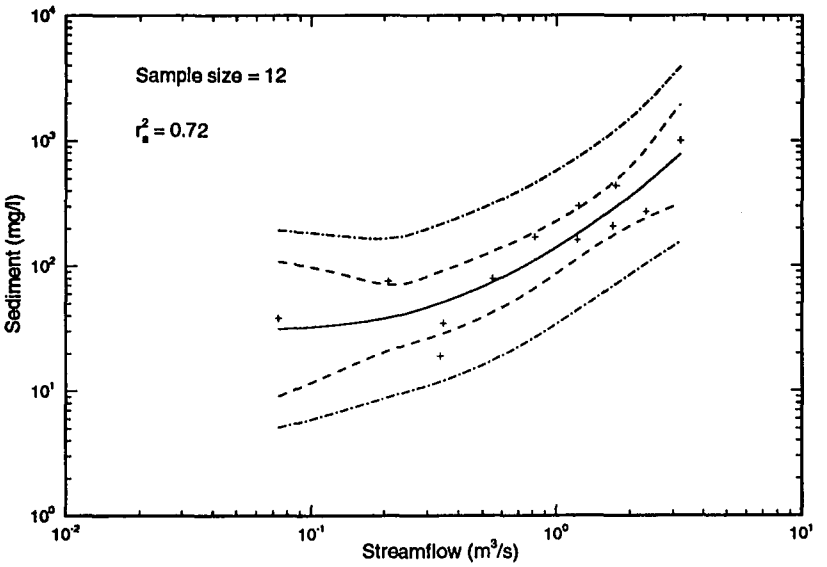


D. Event 1, rising stage

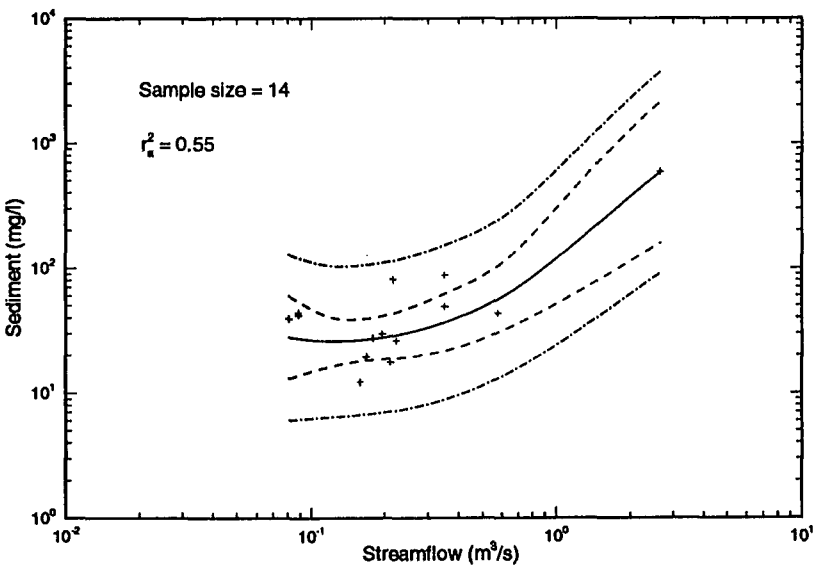


E. Event 1, falling stage

Figure 7. Quadratic model and 95% confidence and prediction intervals for Watershed 12 - continued

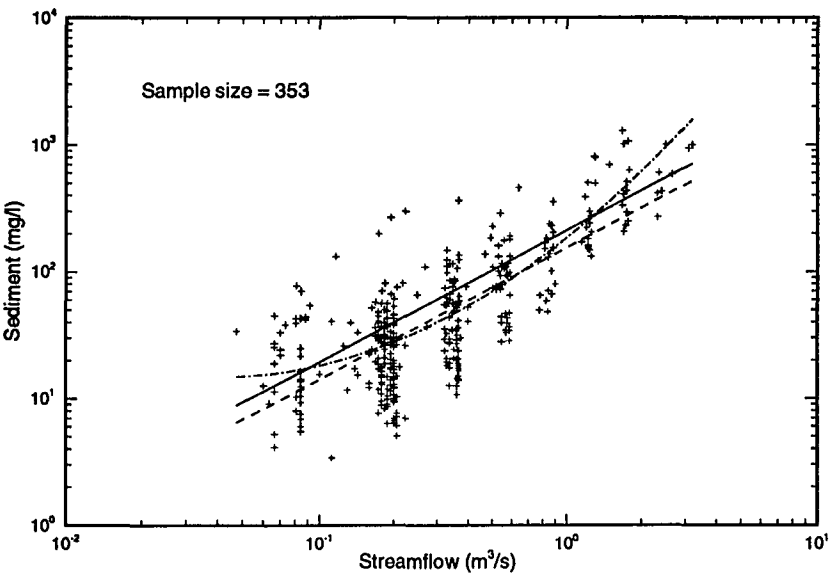


F. Event 3, rising stage



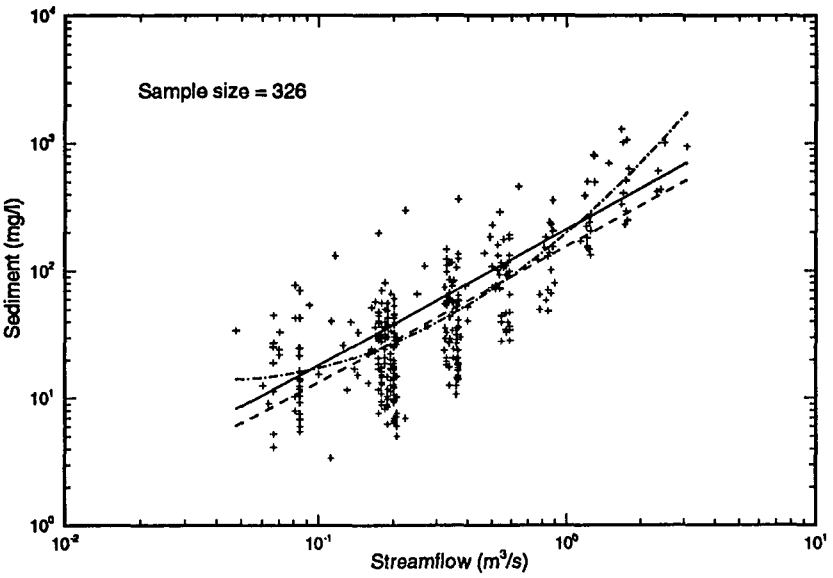
G. Event 3, falling stage

Figure 7. Quadratic model and 95% confidence and prediction intervals for Watershed 12 - continued

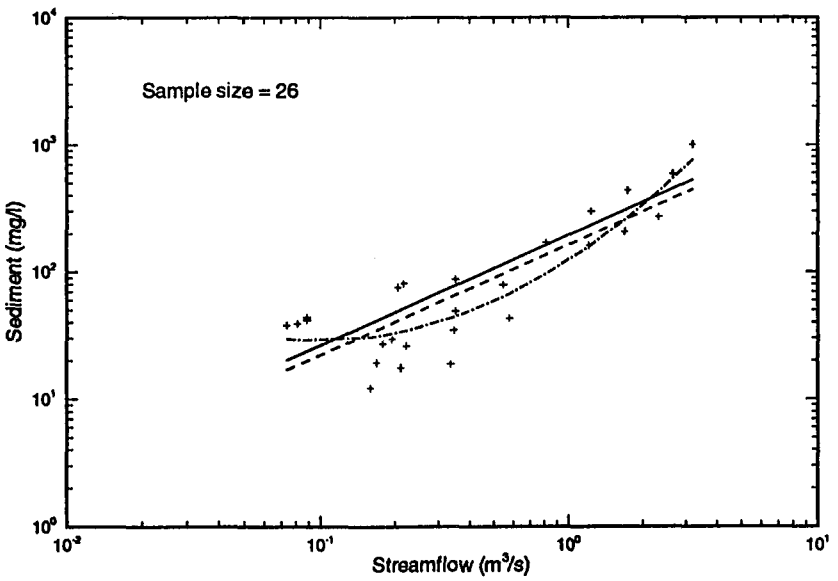


A. Watershed level

Figure 8. Linear, corrected linear, and quadratic models for Watershed 12



B. Event 1



C. Event 3

Figure 8. Linear, corrected linear, and quadratic models for Watershed 12 - continued

Table 6. Comparison of residuals for different models on Watershed 12

Event Type	Stg	*n*	Linear Model	Corrected Linear Model 1	Corrected Linear Model 2	Quadratic Model
-	-	353	30.5	6.1	4.8	5.5
1	-	326	29.7	6.8	6.1	12.1
	R	148	44.6	15.1	13.4	53.0
	F	131	16.0	1.0	2.1	3.4
3	-	26	34.6	7.6	12.3	66.2
	R	12	44.6	0.6	12.1	6.0
	F	14	23.6	8.9	11.7	46.8

Evaluation of SRC Methods

All coefficients of skew (C_s) for the data sets were positive; this indicated that there were more data at low streamflow than at high streamflow, and more data at low sediment than at high sediment in every data set. Most coefficients of kurtosis (K) for streamflow and sediment were greater than 3 (Appendix B). A K value of 3 indicates normal distribution, while a K value greater than 3 indicates there were more data near the mean than the normal distribution.

Improvement of Correlation Coefficients by Partitioning Data

For each vegetative type, the differences between two significant SRCs were tested through the Chow test (Tables 7 and 8). SRCs for ponderosa pine watersheds are shown in Figs. 9, 10, and 11. When data sets of event 1 were partitioned into hydrograph stages, correlation coefficients of SRCs for the rising stage improved significantly, except for Watersheds 12 and 13. In most other cases, the r's were not significantly improved by partitioning data, mainly because there was higher variation in the falling stage and there were only few data for events 2 and 3.

Beschta (1978) found seasonal shift in SRC after the yearly peak streamflow. Walling (1977) reported no significant improvement for the descriptive power of SRCs when partitioning data by season, stage, or season and stage, but there was significant improvement of sediment yield estimates when partitioning data by stage.

Table 7. Test for significance of difference between SRCs (pinyon-juniper)

SRC 1			SRC 2			Degree of Freedom	F	Signifi-
	Event			Event				
Ws	Type	Stg	Ws	Type	Stg	DF	Statistic	cance
Within watershed:								
1	-	-	1	1	-	950	0.09	-
1	-	-	1	2	-	611	3.11	**
1	1	-	1	2	-	515	2.92	-
1	1	-	1	1	R	518	32.94	**
1	2	-	1	2	R	106	7.8	**
2	-	-	2	1	-	963	1.78	-
2	-	-	2	2	-	580	6.72	**
2	1	-	2	2	-	509	9.61	**
2	1	-	2	1	R	597	6.12	**
2	2	-	2	2	R	73	15.15	**
2	2	-	2	2	F	114	6.12	**
2	2	R	2	2	F	61	178.90	**
3	-	-	3	1	-	1179	0.05	-
3	1	-	3	1	R	771	12.56	**
3	1	-	3	1	F	930	6.03	**
3	1	R	3	1	F	561	48.87	**
Among watersheds:								
1	-	-	2	-	-	1040	15.16	**
1	-	-	3	-	-	1132	1.06	-
2	-	-	3	-	-	1126	29.12	**
1	1	-	2	1	-	873	25.34	**
1	1	-	3	1	-	997	0.99	-
2	1	-	3	1	-	1016	49.36	**
1	2	-	2	2	-	151	3.86	**
1	1	R	2	1	R	242	18.35	**
1	1	R	3	1	R	292	6.63	**
2	1	R	3	1	R	352	19.81	**
1	2	R	2	2	R	28	14.05	**

Significance: Significant (**) or insignificant (-) at $\alpha = 0.05$

Table 8. Test for significance of difference between SRCs (ponderosa pine)

SRC 1			SRC 2			Degree of Freedom	F	Signifi-
	Event			Event				
Ws	Type	Stg	Ws	Type	Stg	DF	Statistic	cance
Within watershed:								
8	-	-	8	1	-	1678	0.42	-
8	1	-	8	1	R	1074	13.16	**
8	1	-	8	1	F	1151	3.65	**
8	1	R	8	1	F	573	37.04	**
12	-	-	12	1	-	675	0.29	-
12	-	-	12	3	-	375	27.32	**
12	1	-	12	3	-	348	30.97	**
12	1	-	12	1	R	470	5.91	**
12	1	-	12	1	F	453	8.85	**
12	1	R	12	1	F	275	21.62	**
12	3	-	12	3	R	34	0.14	-
12	3	-	12	3	F	36	1.05	-
12	3	R	12	3	F	22	0.85	-
13	-	-	13	1	-	379	0.71	-
13	1	-	13	1	R	219	5.35	**
13	1	-	13	1	F	246	2.24	-
13	1	R	13	1	F	111	14.02	**
13	3	R	13	3	F	16	21.18	**
14	-	-	14	1	-	901	2.11	-
14	-	-	14	3	-	510	21.35	**
14	1	-	14	3	-	469	303.33	**
14	1	-	14	1	R	568	6.38	**
14	1	-	14	1	F	582	5.24	**
14	1	R	14	1	F	290	15.35	**
14	3	-	14	3	R	57	3.88	**

Table 8. Test for significance of difference between SRCs (ponderosa pine) - continued

SRC 1			SRC 2			Degree of Freedom	F	Signifi-
	Event			Event				
Ws	Type	Stg	Ws	Type	Stg	DF	Statistic	cance
Among watersheds:								
8	-	-	12	-	-	1203	1182.05	**
8	-	-	13	-	-	1054	62.90	**
8	-	-	14	-	-	1323	398.76	**
12	-	-	13	-	-	553	276.22	**
12	-	-	14	-	-	822	308.30	**
13	-	-	14	-	-	673	58.38	**
8	1	-	12	1	-	1150	1095.69	**
8	1	-	13	1	-	1003	43.54	**
8	1	-	14	1	-	1256	346.27	**
12	1	-	13	1	-	501	253.98	**
13	1	-	14	1	-	607	62.92	**
12	3	-	14	3	-	63	10.32	**
8	1	R	12	1	R	394	718.65	**
8	1	F	12	1	F	454	421.66	**
8	1	R	13	1	R	290	35.53	**
8	1	F	13	1	F	394	12.61	**
8	1	R	14	1	R	386	252.55	**
8	1	F	14	1	F	477	145.53	**
12	1	R	13	1	R	188	77.80	**
12	1	F	13	1	F	198	140.71	**
12	1	R	14	1	R	284	103.53	**
12	1	F	14	1	F	281	125.29	**
13	1	R	14	1	R	180	34.55	**
13	1	F	14	1	F	221	35.30	**
12	3	R	13	3	R	16	7.57	**
12	3	F	13	3	F	22	36.91	**
13	3	R	14	3	R	24	6.21	**

Significance: Significant (**) or insignificant (-) at $\alpha = 0.05$

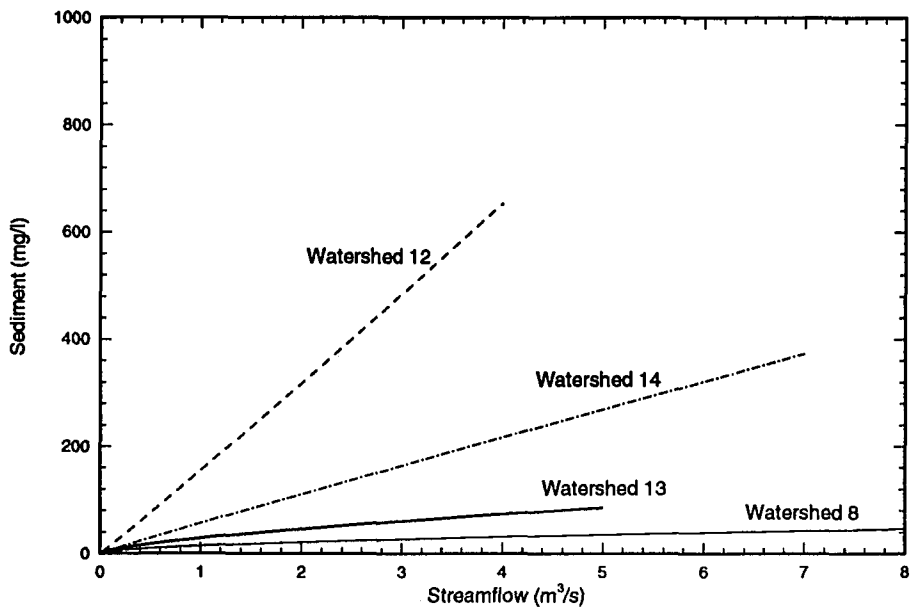
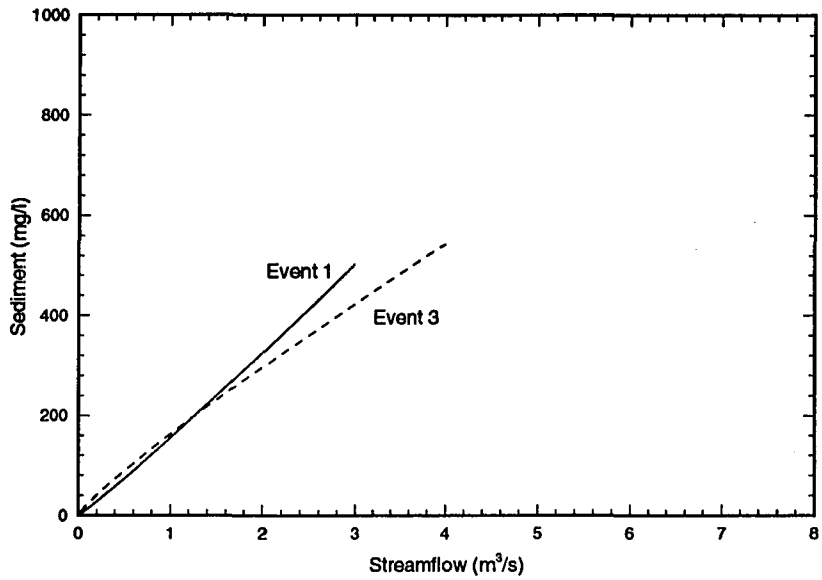
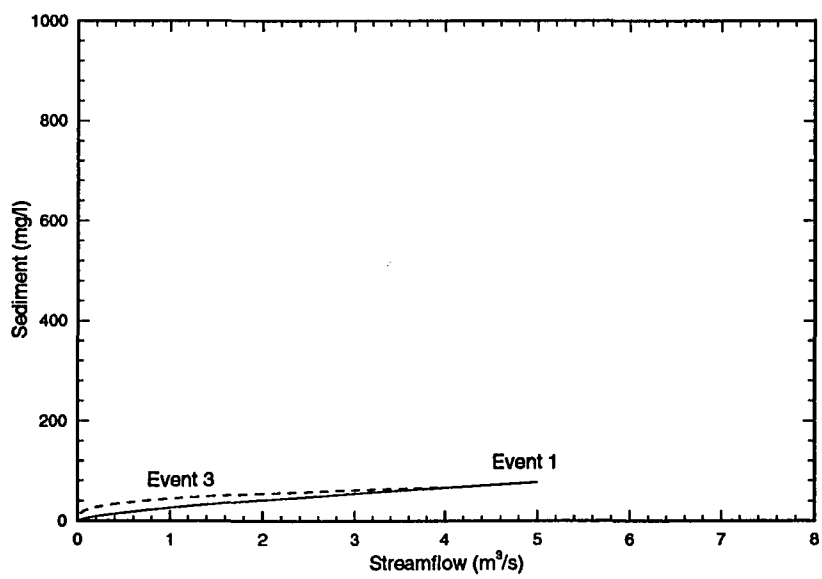


Figure 9. SRCs for the ponderosa pine watersheds

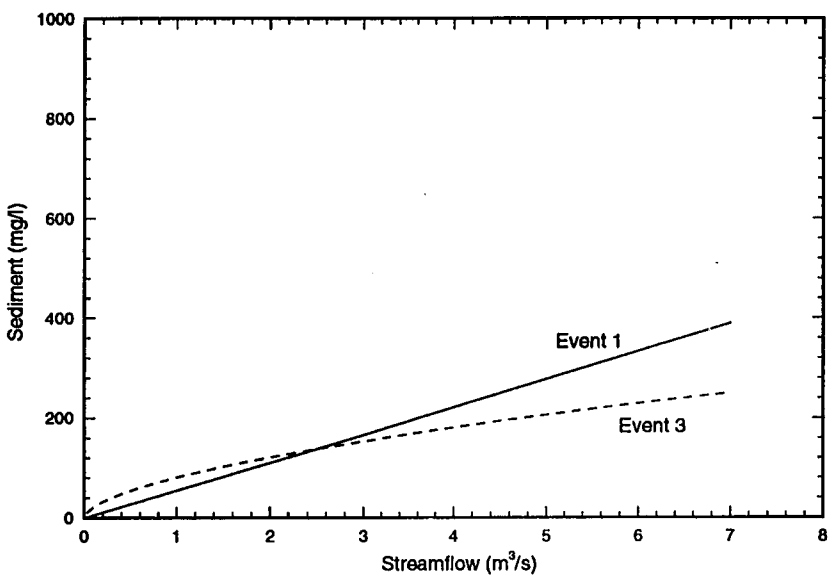


A. Watershed 12



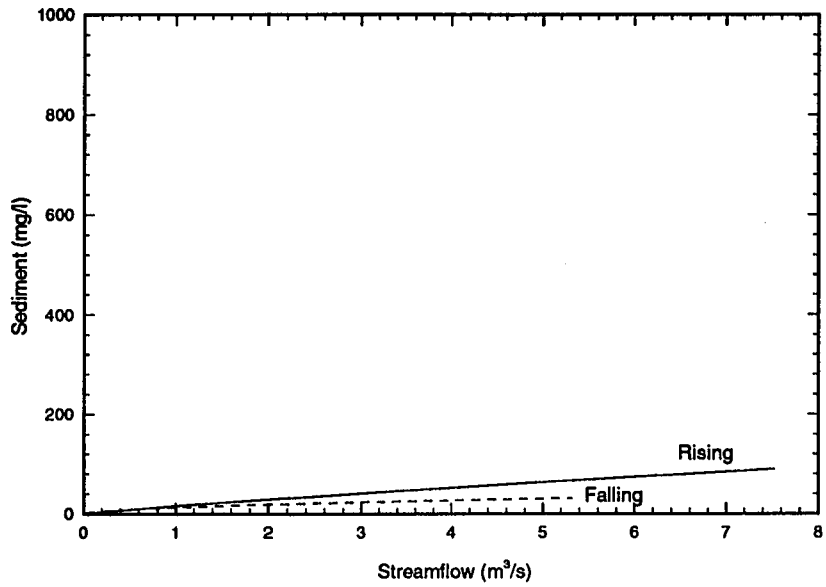
B. Watershed 13

Figure 10. SRCs for events 1 and 3 on the ponderosa pine watersheds

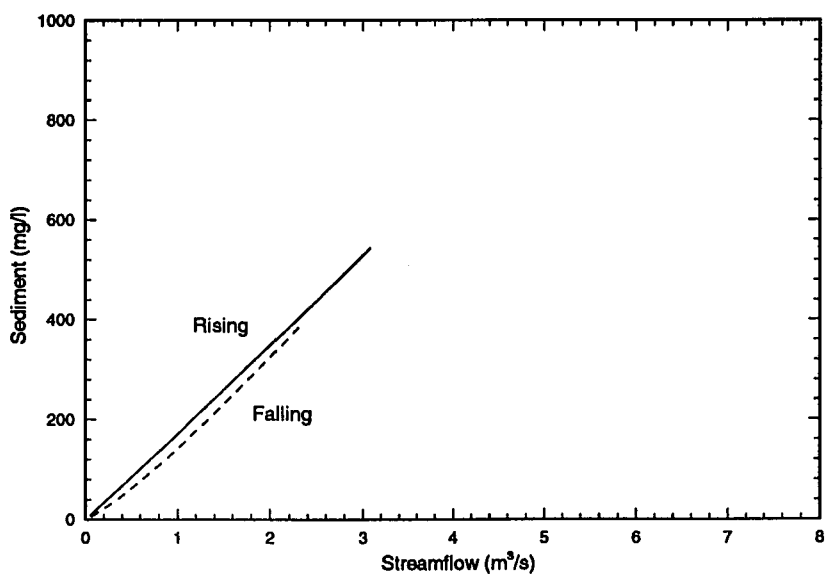


C. Watershed 14

Figure 10. SRCs of events 1 and 3 for the ponderosa pine watersheds - continued

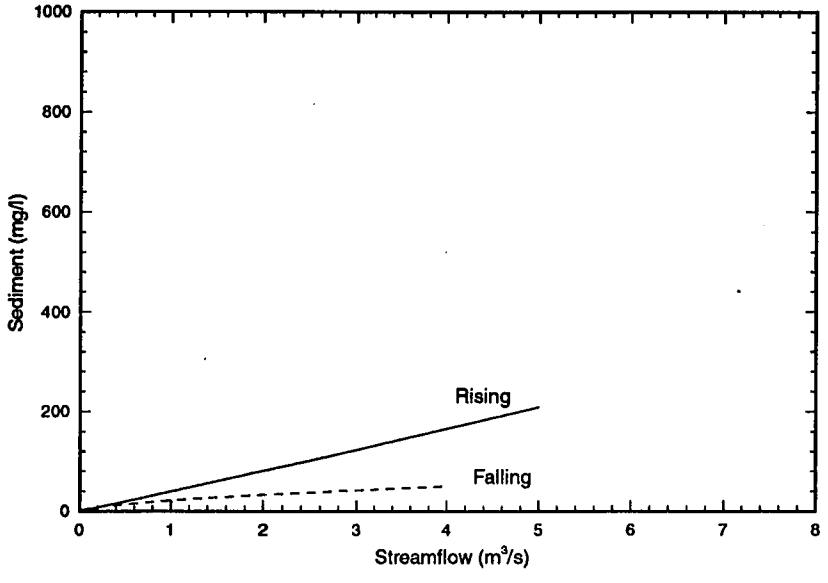


A. Watershed 8, event 1

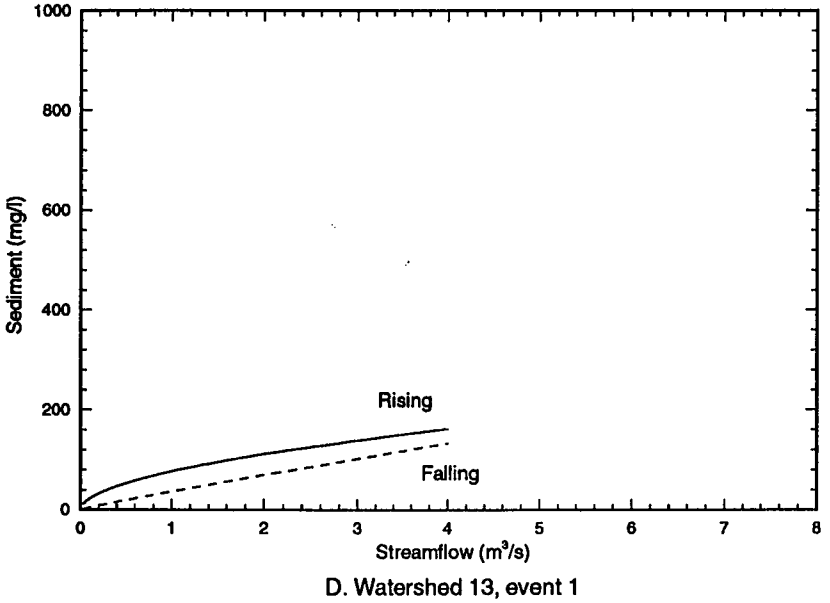


B. Watershed 12, event 1

Figure 11. SRCs for rising and falling stages on the ponderosa pine watersheds

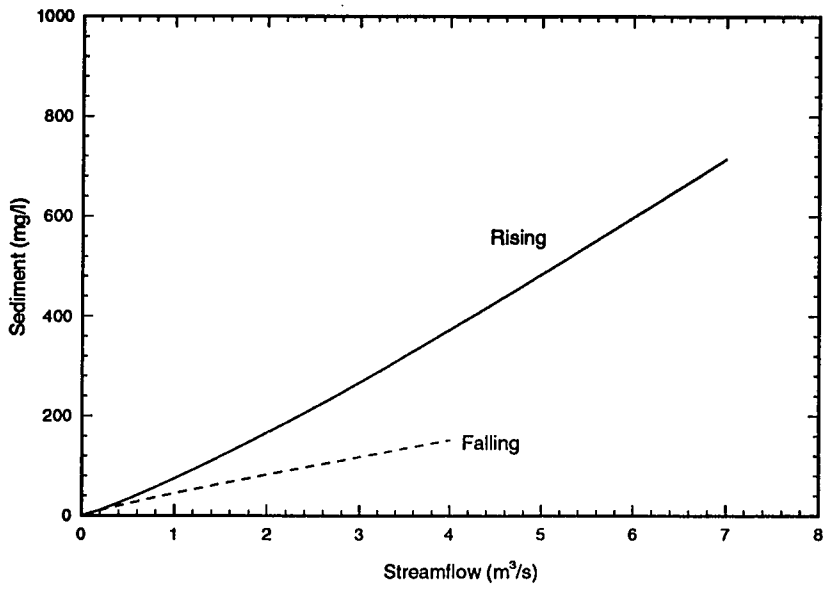


C. Watershed 13, event 1

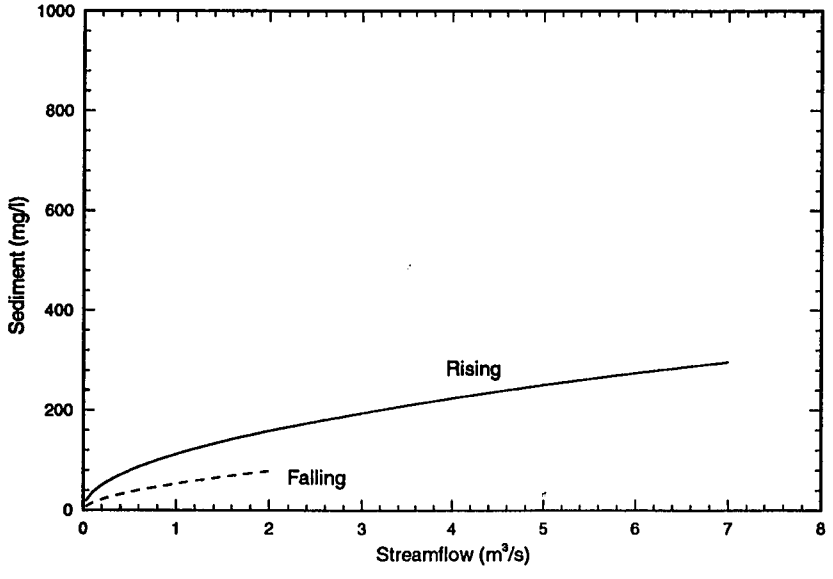


D. Watershed 13, event 1

Figure 11. SRCs for rising and falling stages on the ponderosa pine watersheds - continued



E. Watershed 14, event 1



F. Watershed 14, event 1

Figure 11. SRCs for rising and falling stages on the ponderosa pine watersheds - continued

As partitioning data by event and stage usually produced significantly different SRCs in this study, it increased the descriptive and predictive powers of SRCs even though the correlation coefficients were not raised in some cases.

Accuracy of SRCs in Predicting Sediment Concentrations

The development and use of SRCs are based on the assumption that sediment transport at a point in a stream is a phenomenon depending largely upon streamflow characteristics. Besides vegetative manipulations, streamflow-generating events, and hydrograph stages, sediment concentration estimation errors of SRCs are also associated with SRC developing methods, along with exhaustion effects (hysteretic effects related with relative timing in a season and a hydrograph stage), time rate change in streamflow (dQ/dt), water temperature, and varying pattern of tributary inflow (Colby, 1956; Renard, 1969; Walling and Teed, 1971; Porterfield, 1972).

Vanoni (1975) stated that the relative variation is usually large (it can be 100 times) at low streamflow, and diminishes appreciably at high streamflow, because high streamflow and sediment concentrations for a watershed can be reached by only a very limited combination of hydrologic circumstances.

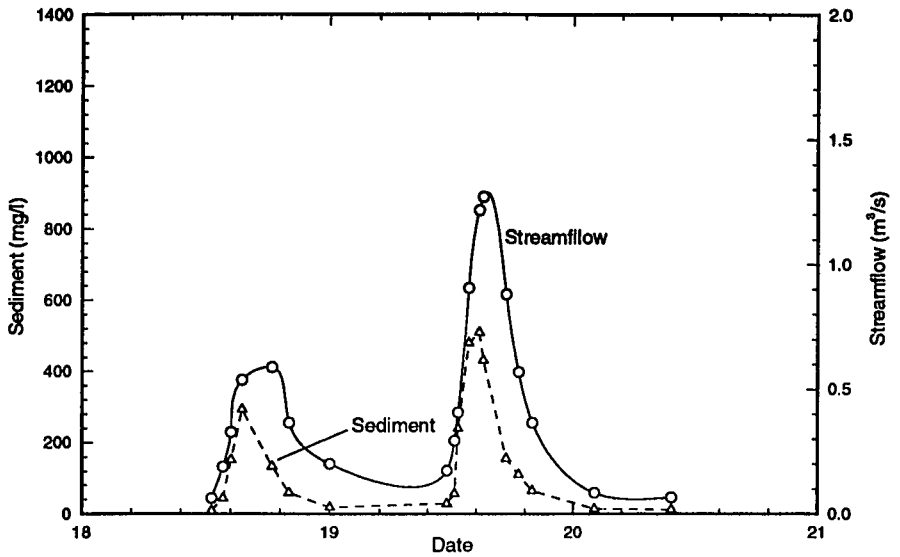
For a given streamflow in the study area, the relative variation of concentrations from lower to upper range was usually over one log cycle (10 times). The higher the streamflow, the lower the relative variation of sediment concentrations; the relative variation was the highest for streamflow less than 0.057 m^3/s. On the contrary, the higher

the streamflow, the higher the absolute variation. The linear model underestimated sediment concentrations, especially for the highest streamflow; the corrected linear model reduced this underestimation. The quadratic model better simulated the trend of streamflow-sediment relation while it also underestimated sediment concentrations.

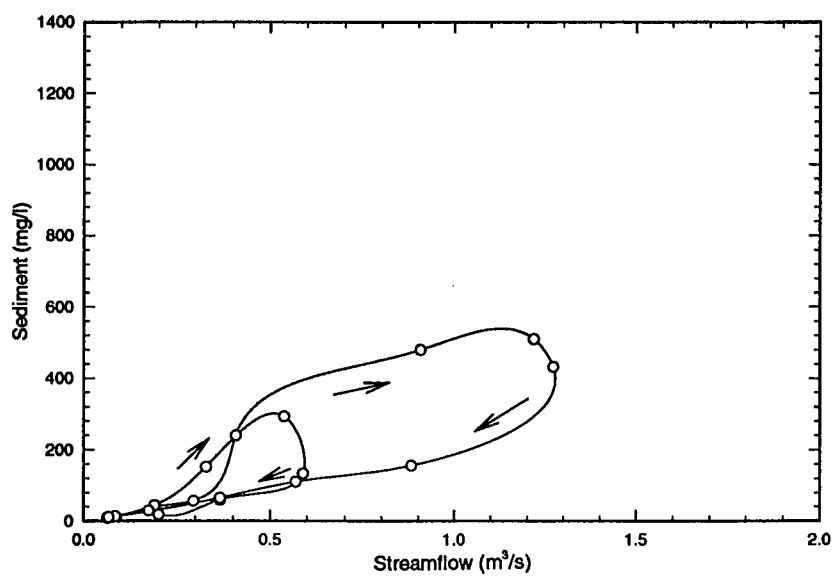
During single streamflow events, streamflow-sediment relationships were usually clockwise loops (Fig. 12), although there were also other relationships, such as single valued, counterclockwise loop, and figure eight (Williams, 1989). Walling and Webb (1987) accounted for some of the exhaustion effects for the changing ratio of direct flow (stormflow) to baseflow (groundwater inflow) in gravel-bed rivers. As baseflow is non-existent on Beaver Creek, the characteristic clockwise looping is mainly due to depletion of available sediment and time rate change in streamflow (dQ/dt).

Differences of Streamflow-Sediment Relationships Between the Two Vegetative Types

SRCs for each watershed and SRCs for event 1 and its corresponding rising stage were all significant in the pinyon-juniper type. About one-half of the remaining SRCs were not significant because of poor relationships between streamflow and sediment, especially in falling stage, and/or small sample size. SRCs also had low values of r_a^2, 0.02-0.54, with about one-half less than 0.10. The fitted standard errors were from 1.70 to 9.79 mg/l. The scatter plots showed a better streamflow-sediment

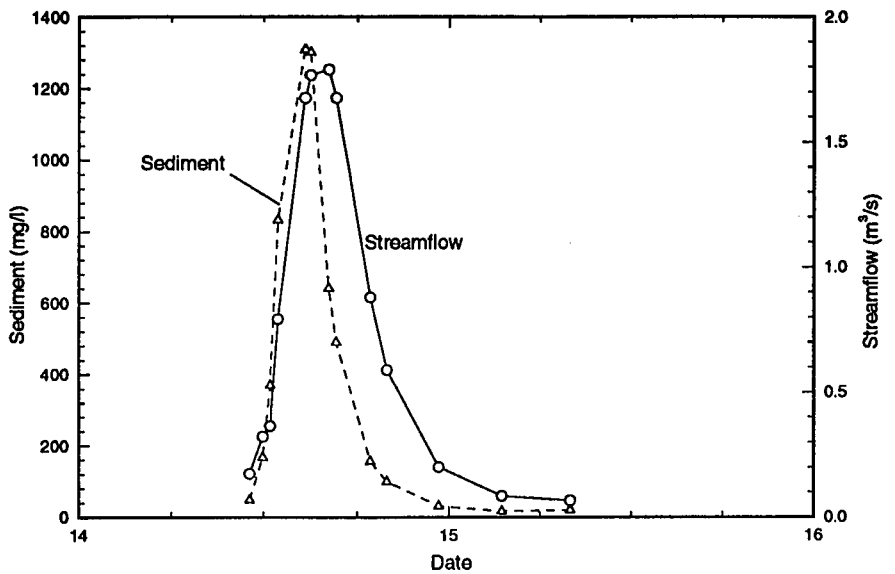


A. Temporal graph, Mar. 18-20, 1975

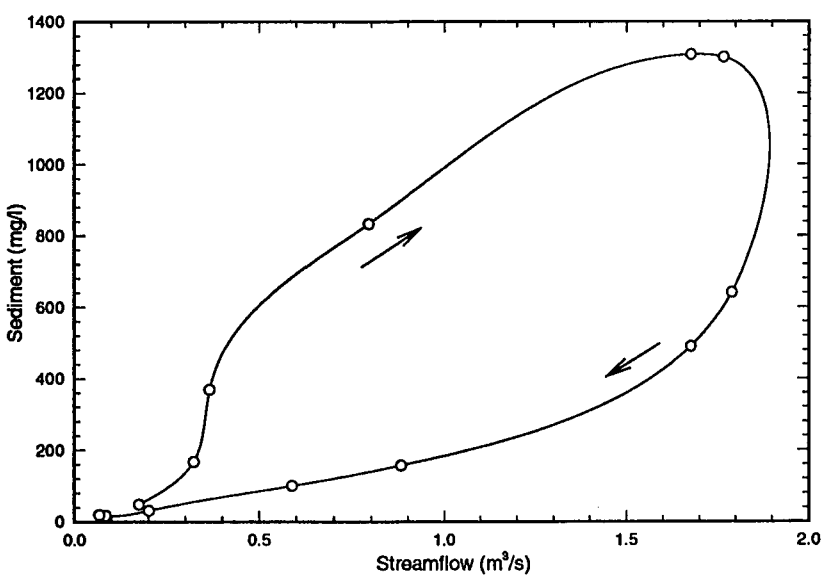


B. Streamflow-sediment relationship, Mar. 18-20, 1975

Figure 12. Streamflow-sediment relationships during single events on Watershed 12

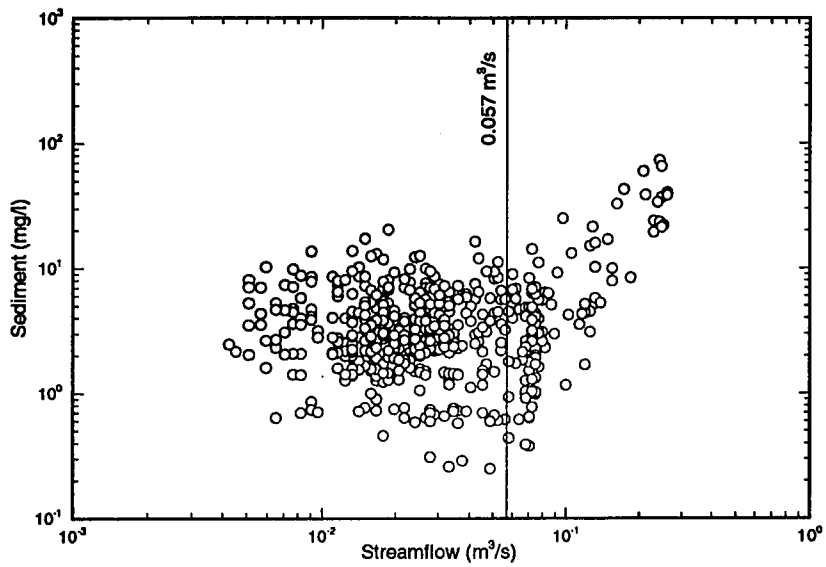


C. Temporal graph, Apr. 14-15, 1975

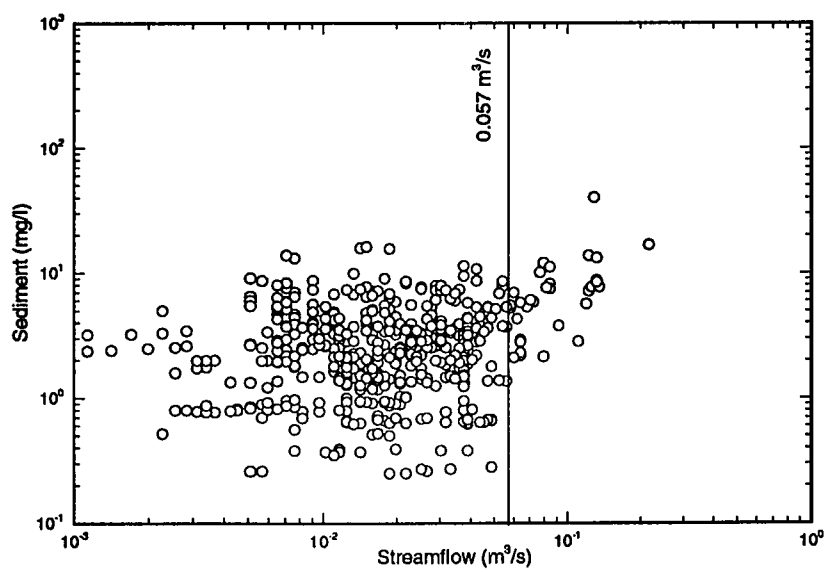


D. Streamflow-sediment relationship, Apr. 14-15, 1975

Figure 12. Streamflow-sediment relationships during single events on Watershed 12 - continued

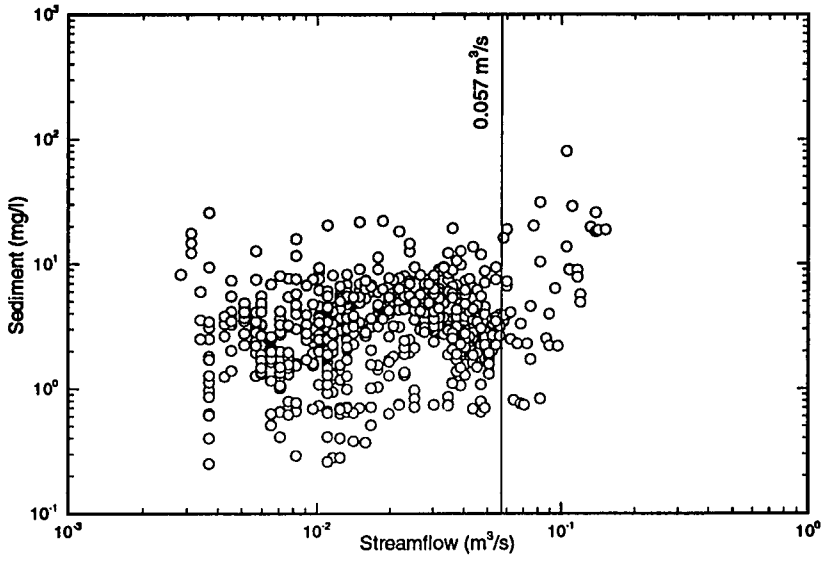


A. Watershed 1



B. Watershed 2

Figure 13. Scatter plots for the pinyon-juniper watersheds



C. Watershed 3

Figure 13. Scatter plots for the pinyon-juniper watersheds - continued

Table 9. SRC parameters and statistics (pinyon-juniper, Q => 0.057 m^3/s)

Ws	Event Type	Stg	n	a	95% Confidence Intervals		b	95% Confidence Intervals		Standard Error SE	r_a^2	F Statistic	Signif-cance
1	-	-	117	0.35	0.23	0.54	2.10	1.77	2.44	8.12	0.58	158.32	**
	1	-	104	0.36	0.23	0.55	2.13	1.77	2.48	8.24	0.57	140.17	**
		R	33	1.67	1.10	2.51	1.49	1.20	1.78	10.68	0.77	110.89	**
		F	67	0.24	0.14	0.39	2.18	1.76	2.61	5.30	0.61	105.89	**
	2	-	12	0.30	0.05	1.94	1.98	0.54	3.43	10.35	0.43	9.42	**
		F	9	0.69	0.17	2.84	1.06	-0.12	2.23	6.20	0.31	4.50	-
2	-	-	32	1.67	0.83	3.34	1.17	0.58	1.76	6.24	0.33	16.36	**
	1	-	21	1.00	0.35	2.81	1.48	0.63	2.34	7.60	0.38	13.15	**
		F	10	0.70	0.31	1.60	1.45	0.70	2.19	1.39	0.68	20.12	**
	2	-	10	1.37	0.49	3.38	1.71	0.63	2.79	1.86	0.58	13.41	**
		F	8	0.90	0.38	2.87	1.22	0.54	1.90	0.39	0.72	19.29	**
3	-	-	42	0.90	0.38	2.87	1.74	0.70	2.27	13.50	0.21	11.58	**
	1	-	41	0.97	0.29	3.23	1.65	0.57	2.72	13.63	0.18	9.58	**
		R	23	3.42	1.02	11.46	1.06	0.05	2.07	3.14	0.15	4.74	**
		F	8	0.13	0.01	1.80	2.61	0.01	5.21	0.36	0.42	6.01	**

Significance: Regression significant (**) or insignificant (-) at $\alpha = 0.05$

relationship at higher streamflow (≥ 0.057 m^3/s, or 2 cfs) (Fig. 13, Appendix B, and Table 9). SRCs were derived from the data sets in this streamflow range. These SRCs had r_a^2 values of 0.15 to 0.77. Half of them were over 0.50. The fitted standard errors ranged from 0.36 to 13.63. SRCs were improved by the exclusion of low streamflow data. Better SRCs can be derived when more data at high streamflow are available.

SRCs for all watersheds, and SRCs for event 1 and its corresponding rising and falling stages, were all significant in the ponderosa pine type. One-half of the remaining SRCs were not significant. The values of r_a^2 ranged from 0.32 to 0.74. The fitted standard errors were 11.03 to 182.39 mg/l.

In the range of SRCs for the pinyon-juniper watersheds (flow < 0.28 m^3/s), sediment concentrations of the control in the pinyon-juniper type (Watershed 2) were higher than that of the control in the ponderosa pine type (Watershed 13) because the ground litter beneath the pinyon-juniper is scare while the ground of ponderosa pine forests is covered with either grass or an accumulation of pine needles (Hansen 1966). However, sediment yields from the ponderosa pine watersheds were higher than the pinyon-juniper watersheds (Brown, et al., 1974; Clary, et al., 1974), as the average precipitation and average streamflow discharge and sediment concentrations were all higher on the ponderosa pine watersheds.

SRCs for the pinyon-juniper type had lower values of r_a^2 than the ponderosa pine type because the average streamflow was lower in the pinyon-juniper type; when streamflow was lower than 0.05 m^3/s, the variation of sediment concentrations in log

scale was high and the correlation of streamflow and sediment was poor in these two vegetative types. Few observations were above 0.05 m^3/s in the pinyon-juniper type. The mean streamflow was from 0.024 to 0.041 m^3/s, with the maximum of 0.261 m^3/s, for the pinyon-juniper watersheds, while the mean streamflow was from 0.456 to 0.663 m^3/s for the ponderosa pine watersheds. When higher streamflow data become available, better SRCs will be derived.

It should be noted that the residuals of SRCs might be autocorrelated. The time intervals of the sediment measurements varied, while time series analysis requires input data with a fixed time interval. Autocorretation could not be tested and time series analysis could not be used in this study.

There was variation in streamflow-sediment relationships among years. Data for each year indicated a need for different SRCs as illustrated by snowmelt-runoff events on Watershed 12 (Fig. 14). Because of this variation, care should be exercised when an SRC is used for prediction in an individual year. As there was no temporal trend, the SRCs are good for descriptive purposes (Weber, 1994). The data of 7-8 years were lumped together to derive the SRCs in this study.

The SRC method is the simplest to calculate sediment concentrations and predict sediment yields. Through appropriate partitioning of the data sets SRCs can produce good results on the ponderosa pine watersheds. Sediment concentrations were not closely related to streamflow discharge at low streamflow on the pinyon-juniper watersheds. SRCs can be used when data at higher streamflow become available.

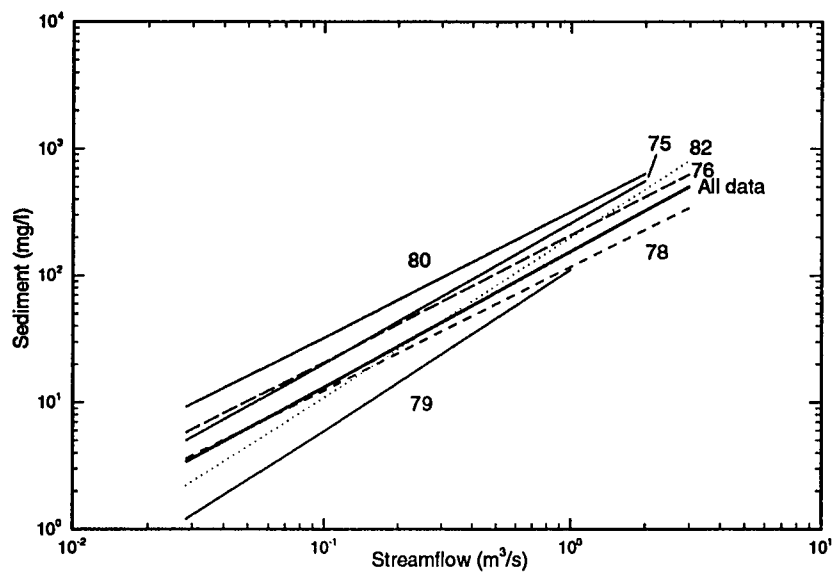


Figure 14. Annual SRCs for event 1 on Watershed 12

Effects of Vegetative Manipulations on Sediment Concentrations

Vegetation binds the soil, promotes infiltration, dissipates raindrop energy, develops greater porosity, and enriches the surface soil (Copeland, 1965). A sediment supply largely depends on the initial depth of loose soil left from previous storms and the amount of soil detachment by raindrop impact, overland flow erosion and channel erosion (Shen and Li, 1976). Sediment is supply-limited on the Beaver Creek watersheds (Lopes and Ffolliott, 1993). Sediment concentrations at the rising stages were higher than at the falling stages for a given level of streamflow discharge because of different time rate changes of streamflow (dQ/dt) and sediment exhaustion. For the same reason, sediment concentrations were also related to the relative timing in a hydrograph stage or season. For a particular hydrograph stage, sediment concentrations tended to be higher in the earlier period than in the later period. The first streamflow events in a season generally produced more sediment. Sediment supply might be unlimited on some watersheds after vegetative manipulations.

Pinyon-Juniper Type

Watershed level. There were no deep or extensive gullies on the pinyon-juniper watersheds; sediment was produced mainly by surface erosion. The magnitude of erosion was low but varied (Williams and Anderson, 1967). Vegetative manipulations promoted surface erosion. The SRC for Watershed 2 was significantly different from SRCs for Watershed 1 and 3. The a's and b's in SRCs for Watershed 1 and 3 were larger than the

a and *b* in the SRC for Watershed 2, respectively, because of vegetative manipulations. The SRC for Watershed 1 was not significantly different from that for Watershed 3.

Event level. The SRC for a watershed was not significantly different from the SRC for event 1 on that watershed because event 1 contributed a major portion of the input data for a watershed, i.e., 83, 87, and 98% for watershed 1, 2, and 3, respectively. The SRC for each watershed was significantly different from the SRC for event 2 on that watershed. The SRC for event 1 was significantly different from the SRC for event 2 on a watershed, except for Watershed 1. The SRC for an event on a watershed was significantly different from the SRC for the same event on another watershed, except for event 1 on Watershed 1 and 3.

For a given streamflow discharge on Watershed 2, sediment concentrations were higher in event 2 (convectional rainfall) than event 1 (snowmelt-runoff), largely because event 2 had higher erosivity and produced more sediment than event 1.

Stage level. Partitioning data at event level by stages produced different SRCs, i.e., the SRC for an event on a watershed was significantly different from the SRC for the corresponding rising or falling stage; and the SRC for the rising stage was significantly different from the SRC for the corresponding falling stage. The SRC for a stage on a watershed was significantly different from the corresponding SRC for another watershed. For a given streamflow discharge, sediment concentrations at the rising stage were higher than those at the falling stage. The SRC for the rising stage had a steeper slope than the corresponding falling stage.

Ponderosa Pine Type

Suspended sediment accounts for approximately 90% of the total sediment yield from the ponderosa pine watersheds (Ward and Baker, 1984). There is little movement of coarse sediment at low streamflow (less than approximately 0.57 m^3/s, or 20 cfs). At higher streamflow, more and more large sand and gravel size material begins to move as bedload (Hansen, 1966). Sediment concentrations from the ponderosa pine watersheds were lower than the broad averages computed by Langbein and Schumm (1958).

Although suspended sediment was the prime contributor to sediment yield, most of the concentrations were below 300 mg/l. Most transport activity was associated with snowmelt. Suspended sediment concentrations were also low except during large thunderstorms or snowmelt events (Ward and Baker, 1984).

Watershed level. SRCs for Watershed 12 and 14 were close to linear (*b* equaling to 1.04 and 0.97, respectively). SRCs were significantly different among these ponderosa pine watersheds. Watershed 12 was clearcut and, as a consequence, had the highest sediment concentrations (Fig. 8). Watershed 14 also had higher sediment concentrations than the control Watershed 13. More overstory removal resulted in higher sediment concentrations 8 years after the treatment. Watershed 8 had the lowest sediment concentrations, partially because it had the largest area and runoff, and, therefore tended to deplete sediment supply. The silvicultural improvement on Watershed 8 also tended to result in lesser erosion and sediment production.

Sediment yield is related with water yield -- the higher the water yield, the higher the sediment yield. Baker (1986a) reported the effects of treatments on the ponderosa pine watersheds on water yield. Water yield increase on Watershed 12 was significant for 7 years, losing significance after recovery and growth of Gambel oak and herbaceous vegetation. On Watershed 8, water yield increase was significant for 6 years. Watershed 14 lost its significant response in water yield in 4 years. Water yield is greatly influenced by the amount and distribution of precipitation, basin physiography, and soil type. It seems that precipitation event dominates over percentage of overstory removal on water yield.

Event level. The SRC for a watershed was not significantly different from the SRC for event 1 on that watershed because most of the data was from event 1. The SRC for a watershed was significantly different from the SRC for event 3 on the same watershed. On a watershed, SRCs for event 1 and event 3 were significantly different from each other (Tables 7 and 8). Fig. 10 shows that, on a watershed, the SRC for event 1 had steeper slope but smaller interception than the SRC for event 3. At lower streamflows (below 1.5-4 m^3/s), sediment concentrations were lower in event 1 than event 3; at higher streamflows, sediment concentrations were higher in event 1 than event 3. The SRC for an event on a watershed was significantly different from the SRC for the same event on another watershed largely due to the effects of vegetative manipulations.

Stage level. Partitioning data at an event level by hydrograph stage produced different SRCs, i.e., the SRC for an event on a watershed was significantly different from the SRC for the corresponding rising or falling stage, and the SRC for the rising stage was significantly different from the SRC for the corresponding falling stage; the exceptions are event 3 on Watershed 12, and between event 3 on Watershed 13 and its falling stage. Sediment concentrations of the rising stage for a given streamflow were higher than the falling stage. The SRC for the rising stage had steeper slope than the corresponding falling stage, except for event 1 on Watershed 12 and event 3 on Watershed 13 (Fig. 11). The SRC for a stage of an event on a watershed was significantly different from the corresponding SRC for another watershed.

Management Implications

More overstory removal results, in general, in higher suspended sediment concentrations. Silvicultural improvement treatments reduce sediment concentrations; therefore, a low level of overstory removal and silvicutural improvement are recommended in timber cutting. Runoff-generating events affect streamflow-sediment relationships and, as a consequence, should be considered in sediment transport modeling. Sediment concentrations are higher on the pinyon-juniper watersheds than the ponderosa pine watersheds at the same level of streamflow; but the average streamflow and sediment concentrations are higher on the ponderosa pine watersheds than the pinyon-juniper watersheds.

CONCLUSIONS

The nonlinear model violates regression assumptions of normality and constant variance; therefore, it is not an appropriate model. The linear model meets regression assumptions of normality and constant variance; however, it can result in some bias when the linear model is retransformed to power function. The bias is small if the regression curve fits the points at the high end of the curve and the variance of the residuals is small. It was concluded that the linear model is the best model for description of the data in this study. A correction factor can eliminate some bias. The corrected linear model is one of the best models to predict sediment concentrations. The quadratic model simulates streamflow-sediment relationship better than the linear model at higher streamflow, and it also has higher r_a^2 than the linear model; however, no correction factor is available to eliminate the retransformation bias.

The SRC method is the simplest and one of the best for description and prediction of streamflow-sediment relationships for the pinyon-juniper type (if higher streamflow data are available) and ponderosa pine types. Partitioning data by streamflow-generating events and hydrograph stages produces significantly different SRCs, which often increases descriptive and predictive powers. The correlation coefficient can increase through partitioning data if the data set is large; r value does not increase if the data set is small. Estimation errors of SRCs are associated with the methods of developing the SRCs, exhaustion effects, time rate change of streamflow, etc. There were more data at low streamflow than high streamflow in this study,

especially in the pinyon-juniper type. Sediment concentrations are not closely related with streamflow at low streamflows. The r_a^2 values are lower in the pinyon-juniper type than the ponderosa pine type. SRCs are improved significantly when the low streamflow data (< 0.057 m^3/s) are excluded. Better SRCs can be derived when more data at high streamflows become available.

In the pinyon-juniper type, Watersheds 1 and 3 had higher sediment concentrations than Watershed 2, due partially to cabling and herbicide treatments. Except for Watershed 1, the SRC for event 1 was significantly different from the SRC for event 2 on a watershed. The SRC for the rising stage was significantly different from the SRC for the corresponding falling stage. For a given streamflow, sediment concentrations were higher at the rising stage than the falling stage. The SRC for the rising stage had a steeper slope than for the corresponding falling stage. SRCs in the ponderosa pine type were significantly different among watersheds. Watershed 12 had the highest sediment concentrations. Watershed 14 had higher sediment concentrations than the control Watershed 13. Watershed 8 had the lowest sediment concentrations. On a given watershed, the SRCs for events 1 and 3 were significantly different from each other; the SRC for event 1 had a steeper slope but smaller interception than the SRC for event 3. SRCs for the rising and falling stages in an event on a watershed were usually significantly different from each other; sediment concentrations were higher in the rising stage than the falling stage for a given streamflow.

The sediment supply on Beaver Creek is limited but it can be unlimited on some watersheds because of vegetative manipulations as on Watershed 12. Vegetation removal disturbs soil and reduces protection of ground surface, and increases sediment production. More basal area removals resulted in higher sediment concentrations.

APPENDIX A

LIST OF SYMBOLS

List of Symbols

a	SRC parameter
A	Channel cross-sectional area (m^2)
a'	$\log a$
a_1	SRC parameter in English units, $a_1 = a(0.0283^b)$
b	SRC parameter
c	SRC parameter in the quadratic model
C	Sediment concentration (mg/l)
$\hat{C}$	Calculated sediment concentration (mg/l)
C_b	Concentration of suspended bed material (mg/l)
CLLS	Corrected linear least squares -- corrected linear model
d	Correction factor in SRC
D	Sediment delivery ratio
E	Error
E_s	Sediment particle mass transfer coefficient (m^2/s)
h	Depth of flow (m)
LLS	Linear least squares -- linear model
MSE	Or s^2, residual mean squares (variance of residuals), MSE is the sample estimate of σ^2, MSE = SSE/(n - 2)
MSR	Mean squares for regression, MSR = SSR (sum squares for regression)
n	Sample size

NLS	Nonlinear least squares -- nonlinear model
p	Number of independent variables
PE_h	Hourly runoff (mm)
PE_s	Seasonal runoff (mm)
Q	Streamflow discharge (m^3/s)
Q_s	Sediment discharge (m-ton/day)
r	Correlation coefficient
r^2	Coefficient of determination
r_a^2	Adjusted coefficient of determination
S	Energy or water surface slope
SD	Standard error
SE	Standard error, $SE = MSE^{0.5}$
SRC	Sediment rating curve
SSE	Residual (error) sum of squares, $SSE = \sum (Y_i - \hat{Y}_i)^2$
SSR	Sum squares for regression, $SSR = \sum (\hat{Y}_i - \overline{Y})^2$
t	Time (s)
T	Total eroded material (m-ton/ha)
V	Average flow velocity (m/s)
V_s	Average velocity of sediment (m/s)
VS	Unit stream power

WNLS Weighted nonlinear least squares

x Distance positive in the direction of flow (m)

X Streamflow discharge (m^3/s)

X' $\log X$

y Local bed elevation (m)

Y Sediment yield (m-ton/ha), concentration (mg/l), or discharge (m-ton/day); any dependent variable

Y' $\log Y$

$\hat{Y}$ Calculated Y

α Significance level

ε Residual, $\varepsilon = Y - \hat{Y}$; for SRC, $\varepsilon_i = \log C_i - \log \hat{C}_i$

σ^2 Variance of residuals, see MSE

λ Porosity of deposited sediment

APPENDIX B

SUMMARY OF STATISTICS FOR STREAMFLOW AND SEDIMENT

Table B1. Summary of statistics for streamflow and sediment (pinyon-juniper)

Ws	Event type	Stg	Streamflow (m^3/s) Mean	SD	Kurt	Skew	Min	Max	Sediment (mg/l) Mean	SD	Kurt	Skew	Min	Max
1	-	-	0.041	0.043	9.83	2.89	0.004	0.261	4.98	7.09	37.97	5.42	0.25	73.07
	1	-	0.042	0.044	9.53	2.87	0.005	0.261	5.09	7.41	37.53	5.47	0.25	73.07
		R	0.066	0.064	2.60	1.88	0.006	0.261	9.92	13.55	9.08	2.92	1.18	73.07
		F	0.036	0.034	13.20	3.03	0.005	0.252	3.79	3.38	22.98	3.59	0.25	33.91
	2	-	0.033	0.032	3.40	2.02	0.004	0.127	3.97	4.07	4.85	2.25	0.73	20.40
		R	0.034	0.043	3.08	1.89	0.009	0.132	6.45	4.43	-0.14	0.81	1.27	15.99
		F	0.032	0.029	4.07	2.05	0.001	0.132	3.26	3.70	10.81	3.23	0.73	20.40
2	-	-	0.025	0.023	14.51	3.04	0.001	0.216	3.27	3.12	39.46	4.36	0.25	40.17
	1	-	0.024	0.021	9.73	2.65	0.001	0.135	3.06	3.06	49.87	5.10	0.25	40.17
		R	0.030	0.026	6.41	2.43	0.005	0.135	3.87	4.35	32.10	4.54	0.35	40.17
		F	0.021	0.018	11.04	2.49	0.001	0.132	2.66	1.88	1.03	1.23	0.25	8.73
	2	-	0.027	0.023	0.76	1.36	0.005	0.084	4.29	2.90	-0.07	0.85	0.79	12.01
		R	0.024	0.029	1.39	1.63	0.005	0.084	8.17	1.99	-0.39	0.71	5.95	12.01
		F	0.027	0.022	0.84	1.36	0.006	0.084	3.41	2.28	1.73	1.29	0.79	11.39
3	-	-	0.026	0.023	6.35	2.14	0.003	0.151	4.33	4.98	91.51	7.20	0.25	80.17
	1	-	0.026	0.023	5.70	2.02	0.003	0.151	4.30	4.93	101.74	7.72	0.25	80.17
		R	0.032	0.027	5.38	2.14	0.003	0.151	5.64	7.16	58.92	6.33	0.26	80.17
		F	0.023	0.020	3.25	1.61	0.004	0.119	3.41	2.21	3.73	1.40	0.25	15.91
	2	-	0.018	0.008	8.06	1.90	0.003	0.049	3.64	4.91	5.75	2.46	0.28	20.48
		R	0.020	0.004	4.60	-1.90	0.011	0.024	6.82	8.02	-0.81	1.06	0.63	20.48
		F	0.017	0.008	8.52	2.81	0.003	0.049	2.39	2.20	0.92	1.37	0.28	7.70

Event type:
1 = Snowmelt-runoff
2 = Conventional rainfall
3 = Frontal rainfall

Stg (hydrograph stage):
- = Entire hydrograph
R = Rising
F = Falling

Table B2. Summary of statistics for streamflow and sediment (ponderosa pine)

	Event		Streamflow (m^3/s)						Sediment (mg/l)					
Ws	type	Stg	Mean	SD	Kurt	Skew	Min	Max	Mean	SD	Kurt	Skew	Min	Max
8	-	-	0.663	0.797	18.48	3.66	0.034	7.528	14.03	22.30	96.40	8.10	1.42	352.29
	1	-	0.673	0.806	17.99	3.62	0.034	7.528	13.99	22.40	97.47	8.17	1.42	352.29
		R	1.032	1.081	10.79	2.95	0.063	7.528	21.32	35.99	42.49	5.76	1.53	352.29
		F	0.692	0.718	9.84	2.73	0.034	5.320	12.55	12.69	17.94	3.55	1.42	110.65
	3	-	0.349	0.265	2.18	1.54	0.077	1.146	15.03	19.25	21.02	4.40	3.81	105.09
		R	0.541	0.334	-0.40	0.64	0.121	1.146	22.08	31.68	8.12	2.82	5.88	105.09
		F	0.244	0.150	3.75	1.99	0.134	0.577	10.70	5.72	0.28	0.79	3.81	21.29
12	-	-	0.456	0.503	7.74	2.60	0.048	3.198	100.00	177.45	16.80	3.83	3.45	1307.65
	1	-	0.434	0.455	7.72	2.56	0.048	3.085	95.32	172.60	18.66	4.02	3.45	1307.65
		R	0.512	0.519	6.72	2.45	0.048	3.085	131.47	226.95	10.41	3.18	7.67	1307.65
		F	0.439	0.425	4.21	2.01	0.067	2.352	73.42	111.42	12.78	3.23	3.45	705.27
	3	-	0.742	0.881	1.63	1.59	0.074	3.198	152.09	227.61	8.18	2.72	12.38	1017.38
		R	1.145	0.957	0.29	0.92	0.074	3.198	236.01	277.09	6.16	2.32	19.24	1017.38
		F	0.396	0.664	12.65	3.50	0.081	2.655	80.16	150.31	13.31	3.60	13.38	596.71
13	-	-	0.693	0.916	5.49	2.32	0.034	5.009	33.12	69.19	42.71	5.78	1.00	655.80
	1	-	0.609	0.825	7.95	2.63	0.034	5.009	29.96	71.65	43.48	6.00	1.00	655.80
		R	1.076	1.090	4.28	2.09	0.140	5.009	63.46	110.48	19.43	4.00	3.19	655.80
		F	0.726	0.803	3.16	1.83	0.034	3.736	28.28	65.64	40.68	5.95	1.35	503.90
	3	-	1.294	1.272	0.10	1.18	0.117	4.075	55.76	42.63	0.47	1.12	6.15	157.42
		R	1.262	1.243	1.52	1.42	0.274	3.792	85.62	54.83	-2.17	0.25	26.10	157.42
		F	1.452	1.212	0.40	1.19	0.300	4.075	34.90	25.84	-0.18	0.95	6.15	85.96
14	-	-	0.528	0.798	25.84	4.58	0.048	6.679	46.20	99.39	31.16	5.11	1.26	873.86
	1	-	0.520	0.775	25.51	4.53	0.048	6.679	44.32	101.49	31.49	5.19	1.26	873.86
		R	0.779	1.119	12.69	3.40	0.057	6.679	84.82	159.73	10.58	3.18	3.31	873.86
		F	0.537	0.565	9.73	2.76	0.054	3.934	34.25	55.41	31.37	4.83	2.15	488.92
	3	R	0.803	1.376	14.71	3.69	0.077	6.283	96.82	91.88	9.30	2.82	18.86	429.58
		-	0.618	1.015	25.13	4.64	0.077	6.283	66.03	73.47	15.00	3.40	10.85	429.58
		F	0.765	0.517	-0.86	0.30	0.143	1.653	50.77	36.78	-1.32	0.64	11.21	106.68

Table B3. Summary of statistics for streamflow and sediment (pinyon-juniper, $Q >= 0.057$ m^3/s)

Ws	Event type	Stg	Streamflow (m^3/s) Mean	SD	Kurt	Skew	Min	Max	Sediment (mg/l) Mean	SD	Kurt	Skew	Min	Max
1	-	-	0.102	0.056	1.84	1.71	0.058	0.261	8.88	13.33	8.36	2.79	0.38	73.07
	1	-	0.101	0.056	1.86	1.79	0.058	0.261	8.97	13.64	8.37	2.80	0.38	73.07
		R	0.123	0.070	-0.90	0.88	0.058	0.261	17.92	17.36	2.40	1.62	3.97	73.07
		F	0.092	0.046	5.79	2.54	0.064	0.252	4.88	9.23	30.00	5.10	0.38	65.61
	2	-	0.104	0.030	-1.60	-0.58	0.058	0.127	5.50	5.38	0.24	1.27	1.17	15.99
		F	0.095	0.030	-2.03	-0.02	0.058	0.132	2.73	1.72	-0.30	1.17	1.17	5.78
2	-	-	0.093	0.035	3.19	1.52	0.058	0.216	7.87	6.94	15.38	3.46	2.10	40.17
	1	-	0.096	0.030	-1.95	0.04	0.060	0.135	7.74	8.21	13.06	3.34	2.10	40.17
		R	0.105	0.030	-1.71	-0.65	0.060	0.135	11.29	9.98	8.74	2.87	5.66	40.17
		F	0.086	0.029	-1.05	0.83	0.060	0.132	3.83	2.57	1.07	1.62	2.10	8.73
	2	-	0.073	0.011	-1.74	-0.40	0.058	0.084	7.25	2.59	-0.17	0.93	4.29	12.01
		F	0.071	0.011	-2.00	0.06	0.058	0.084	6.18	1.38	-1.47	0.31	4.29	8.16
3	-	-	0.088	0.028	-0.68	0.69	0.058	0.151	10.55	13.69	16.05	3.49	0.74	80.17
	1	-	0.087	0.027	-0.49	0.75	0.058	0.151	10.18	13.64	17.25	3.67	0.74	80.17
		R	0.094	0.030	-1.12	0.35	0.058	0.151	15.95	16.04	12.08	3.13	2.30	80.17
		F	0.085	0.018	1.13	1.07	0.064	0.119	2.68	1.64	-1.63	0.23	0.74	4.93

APPENDIX C

SRCs AND 95% CONFIDENCE AND PREDICTION INTERVALS

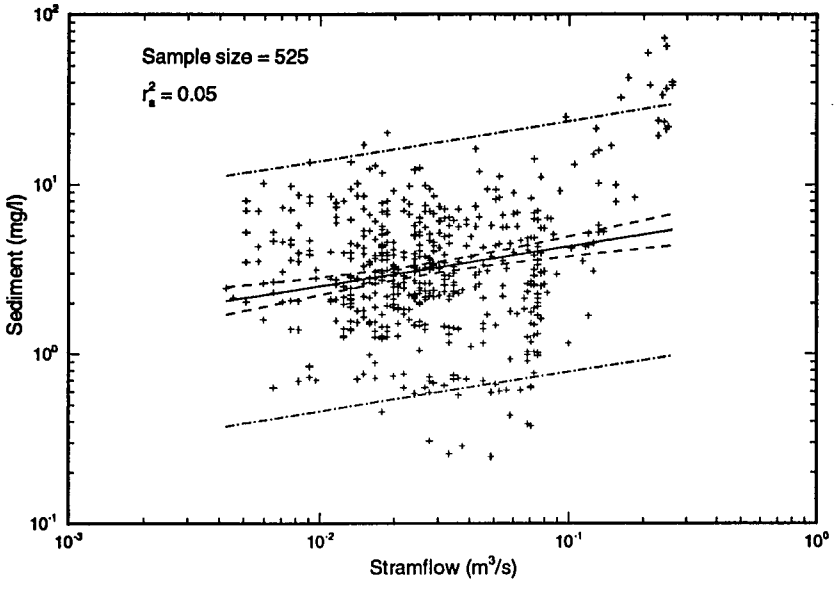


Figure C1. SRC and 95% confidence and prediction intervals for Watershed 1

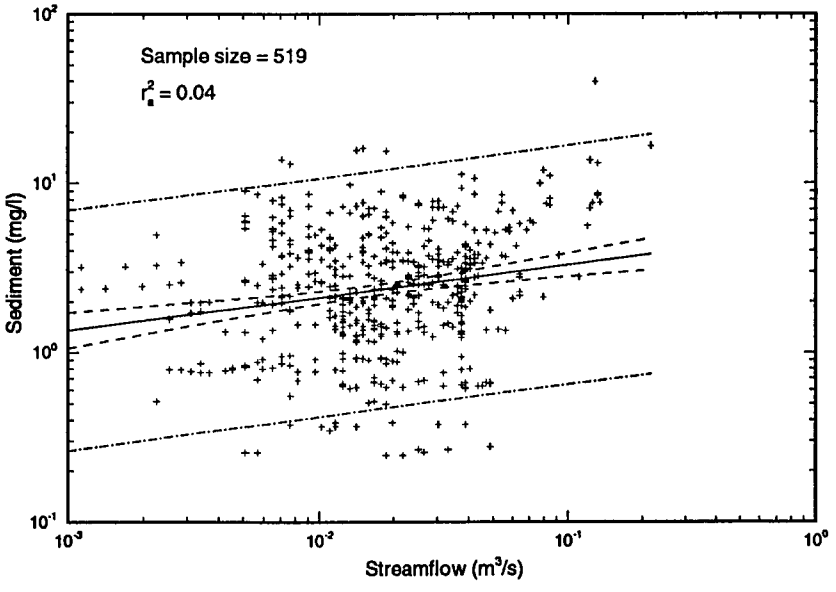


Figure C2. SRC and 95% confidence and prediction intervals for Watershed 2

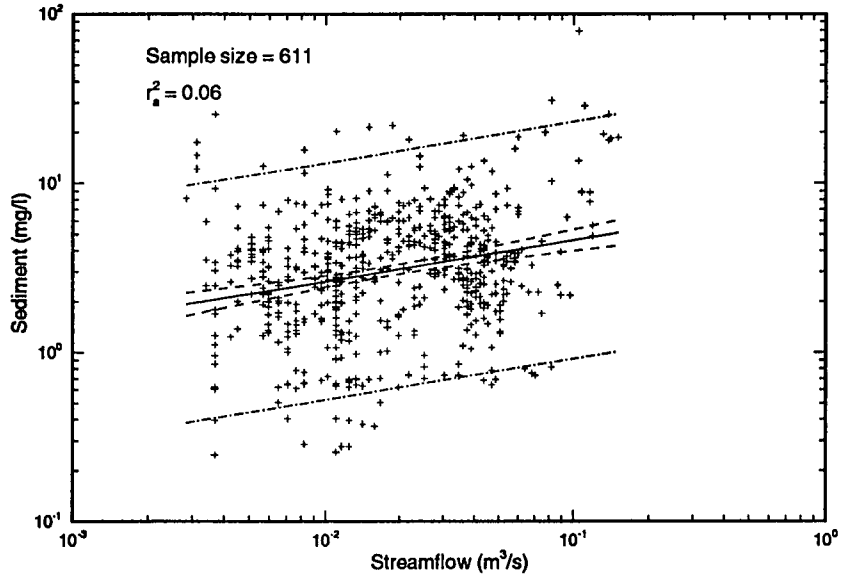


Figure C3. SRC and 95% confidence and prediction intervals for Watershed 3

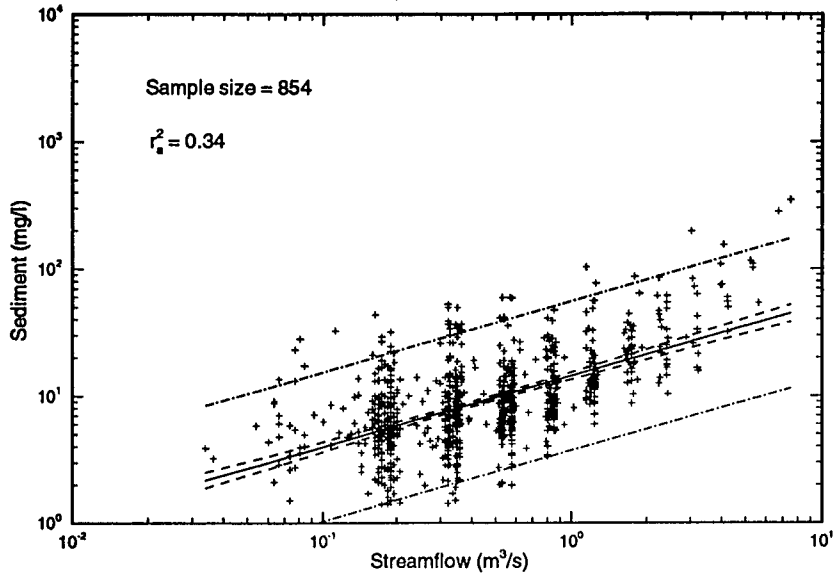


Fig C4. SRC and 95% confidence and prediction intervals for Watershed 8

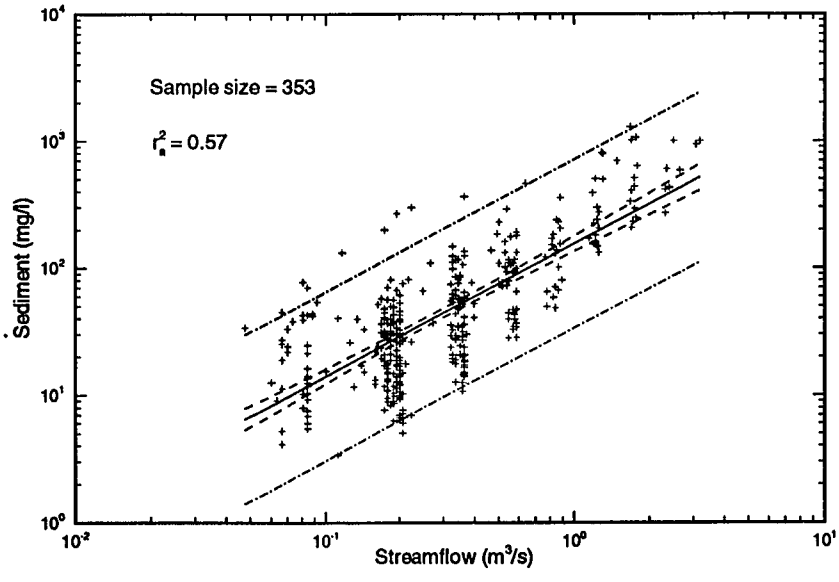


Figure C5. SRC and confidence and prediction intervals for Watershed 12

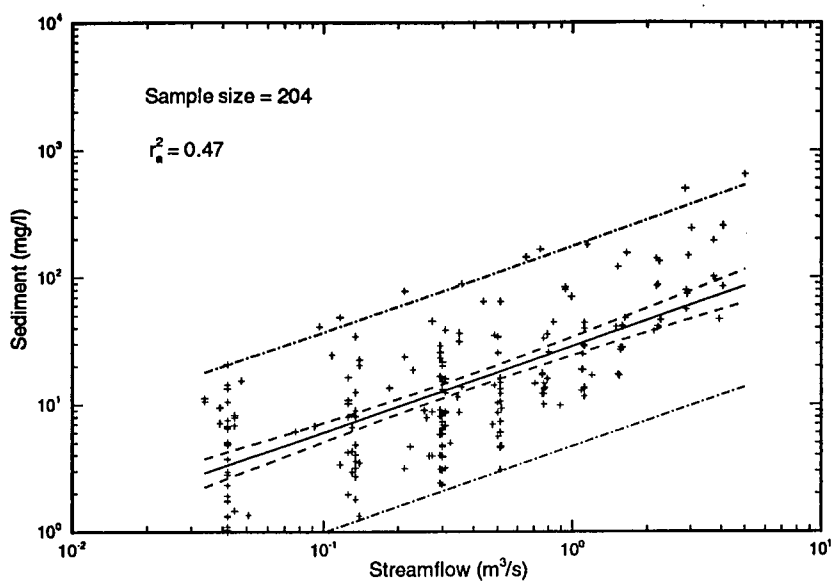


Figure C6. SRC and 95% confidence and prediction intervals for Watershed 13

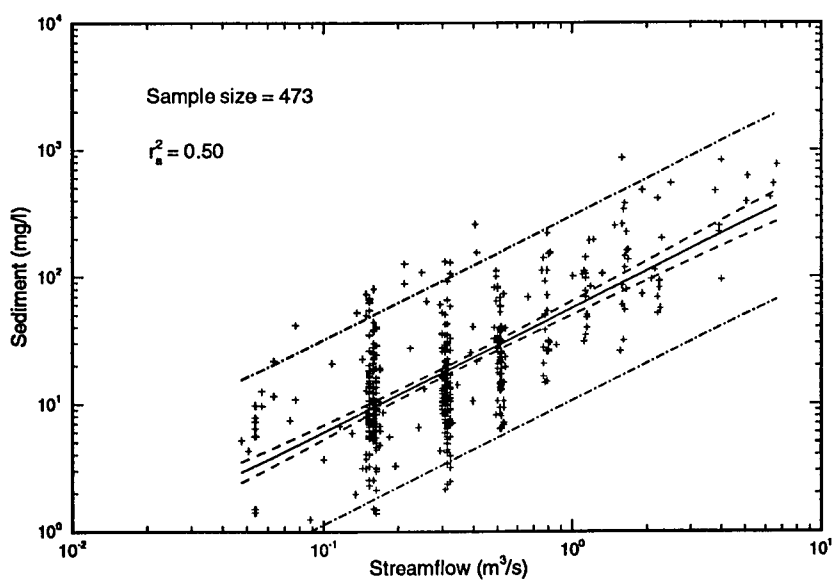


Figure C7. SRC and 95% confidence and prediction intervals for Watershed 14

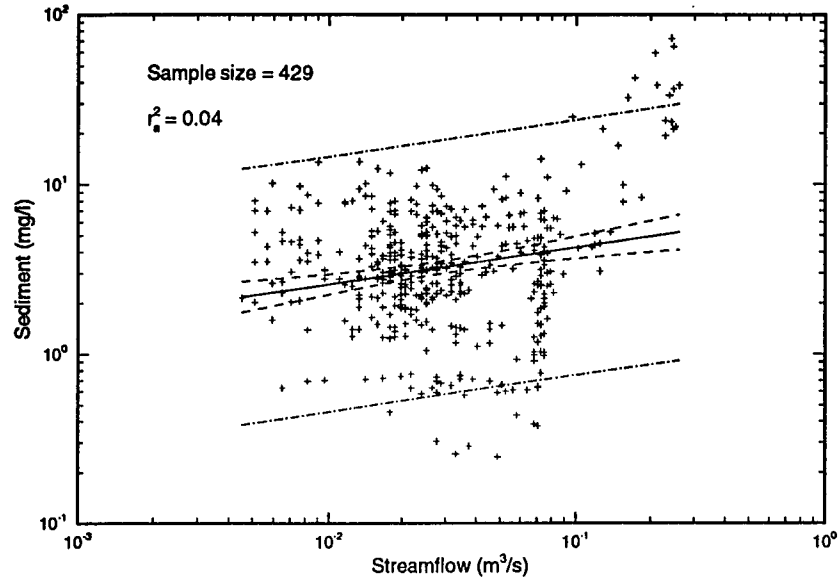


Figure C8. SRC and 95% confidence and prediction intervals for event 1 on Watershed 1

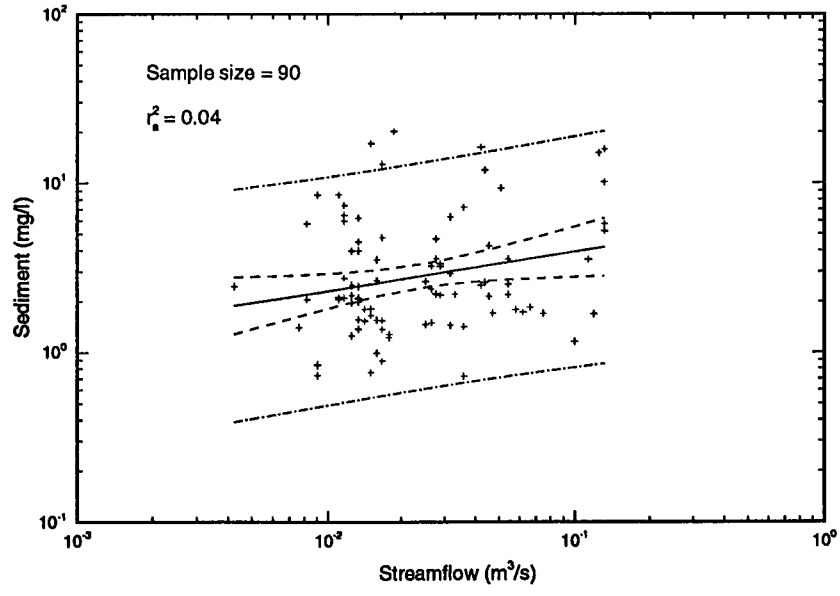


Figure C9. SRC and 95% confidence and prediction intervals for event 2 on Watershed 1

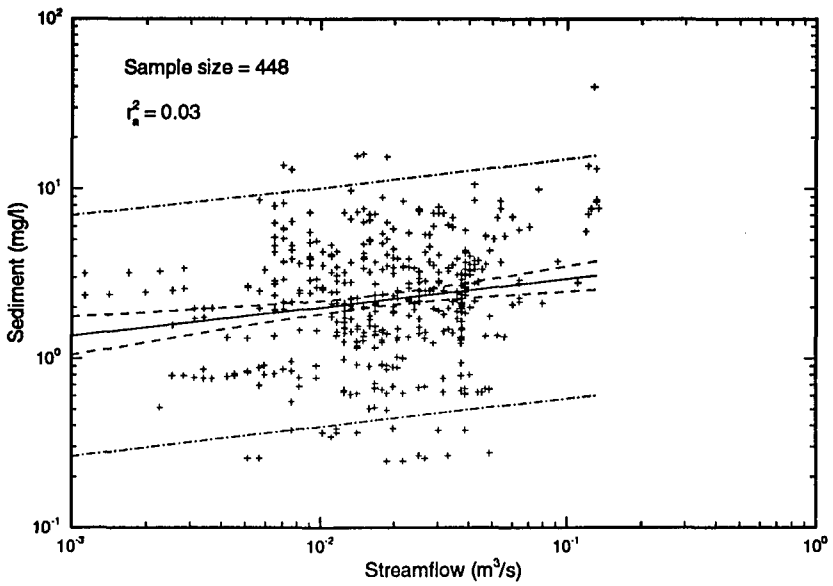


Figure C10. SRC and 95% confidence and prediction intervals for event 1 on Watershed 2

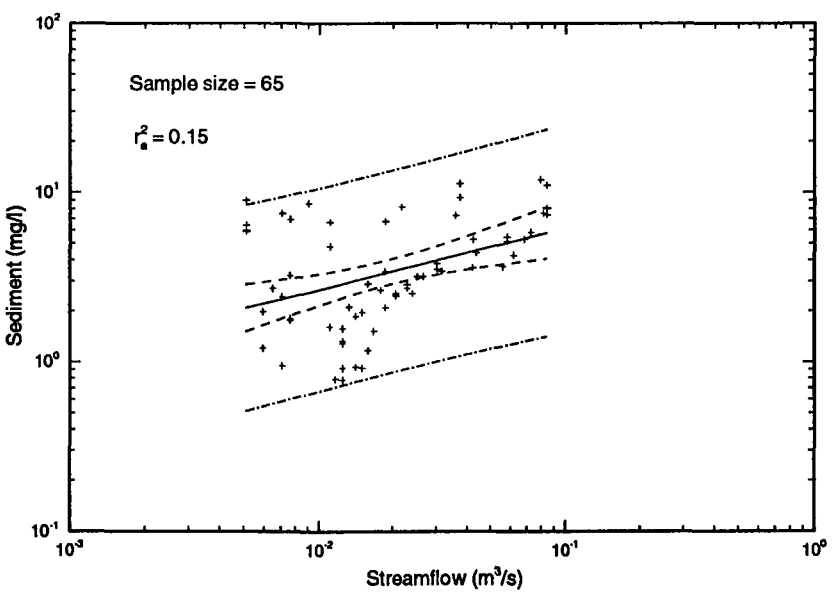


Figure C11. SRC and 95% confidence and prediction intervals for event 2 on Watershed 2

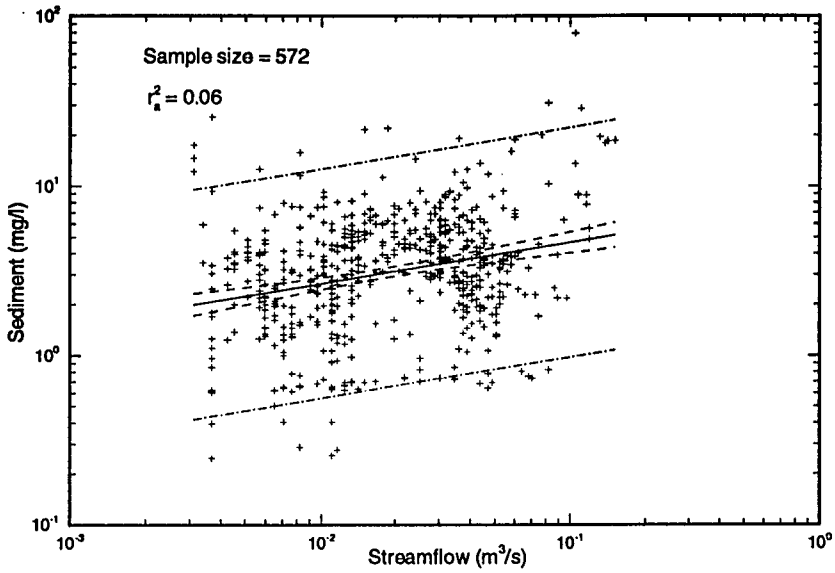


Figure C12. SRC and 95% confidence and prediction intervsls for event 1 on Watershed 3

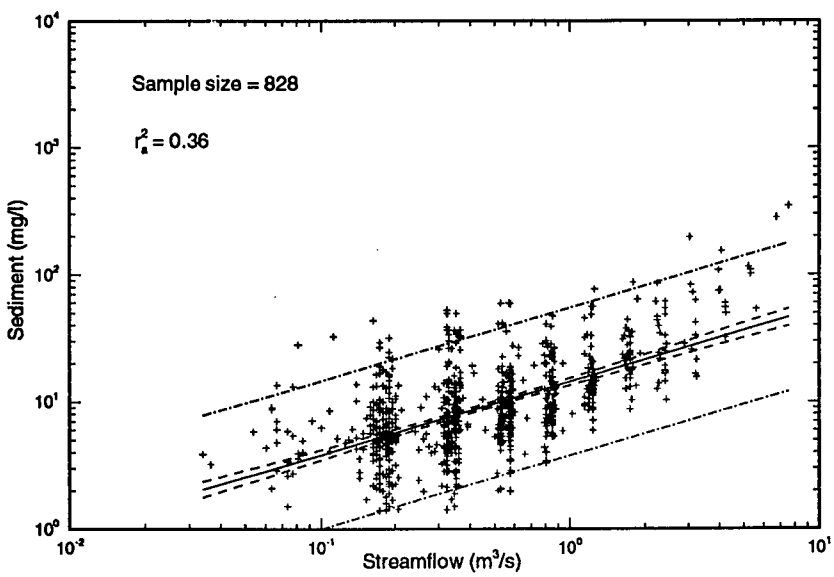


Figure C13. SRC and 95% conficence and prediction intervals for event 1 on Watershed 8

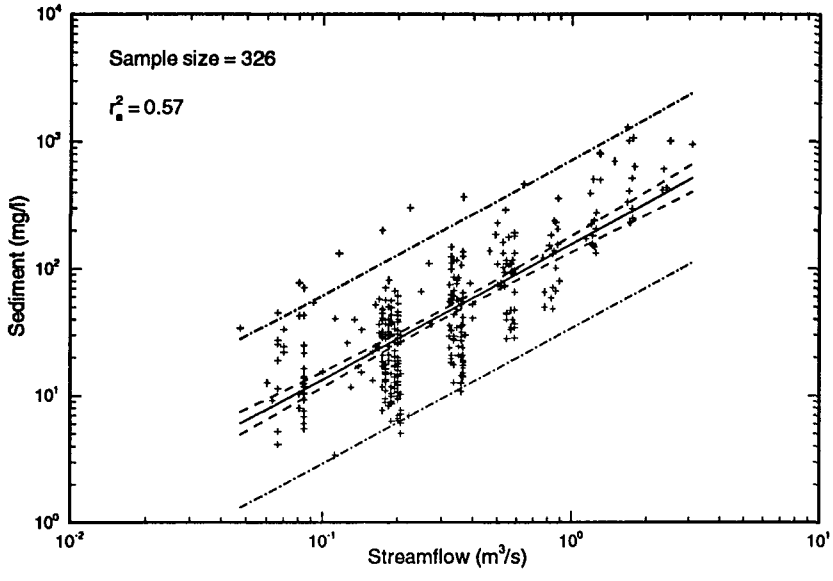


Figure C14. SRC and 95% confidence and prediction intervals for event 1 on Watershed 12

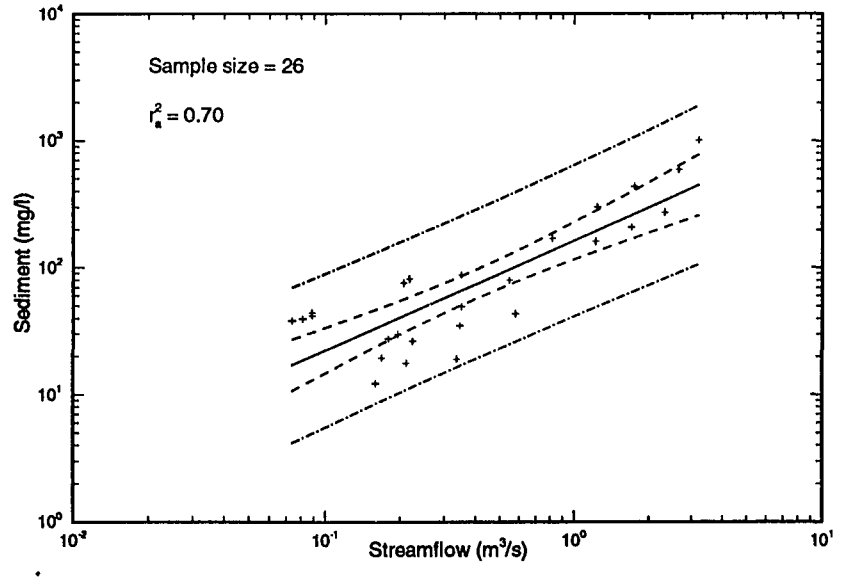


Figure C15. SRC and 95% confidence and prediction intervals for event 3 on Watershed 12

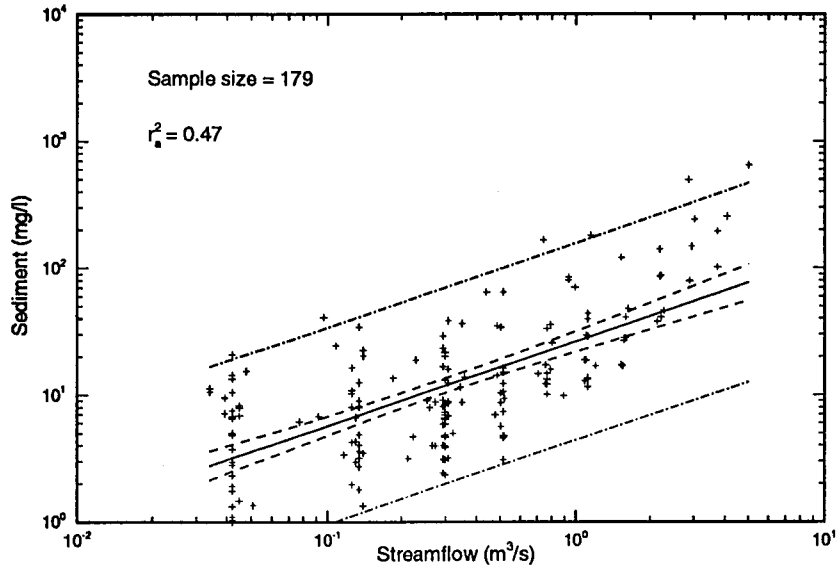


Figure C16. SRC and 95% confidence and prediction intervals for event 1 on Watershed 13

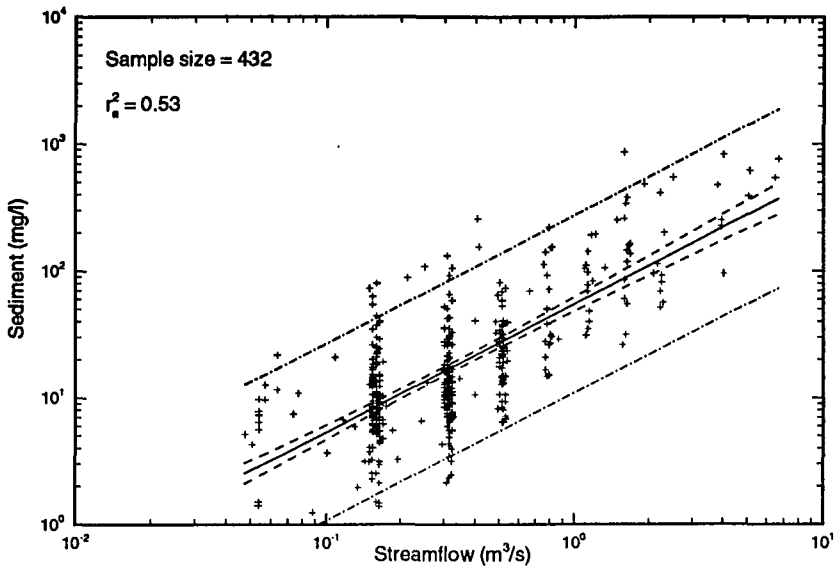


Figure C17. SRC and 95% confidence and prediction intervals for event 1 on Watershed 14

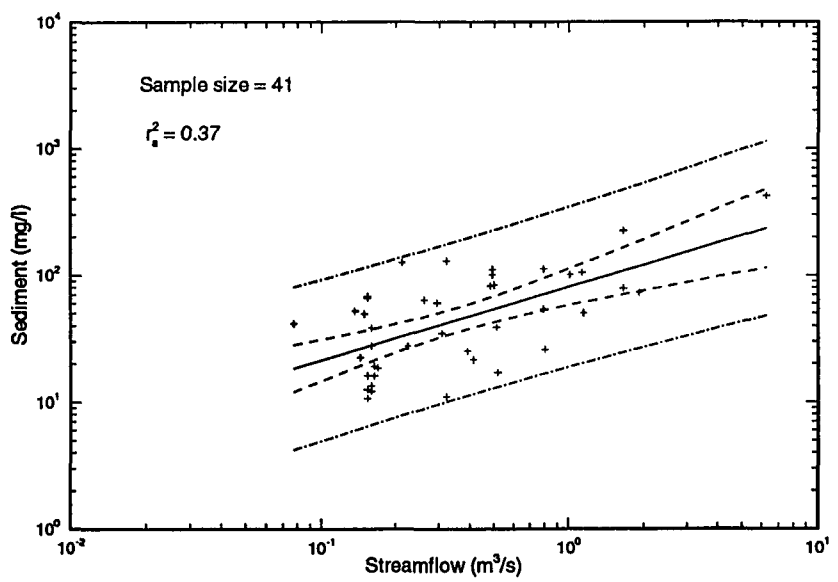


Figure C18. SRC and 95% confidence and prediction intervals for event 3 on Watershed 14

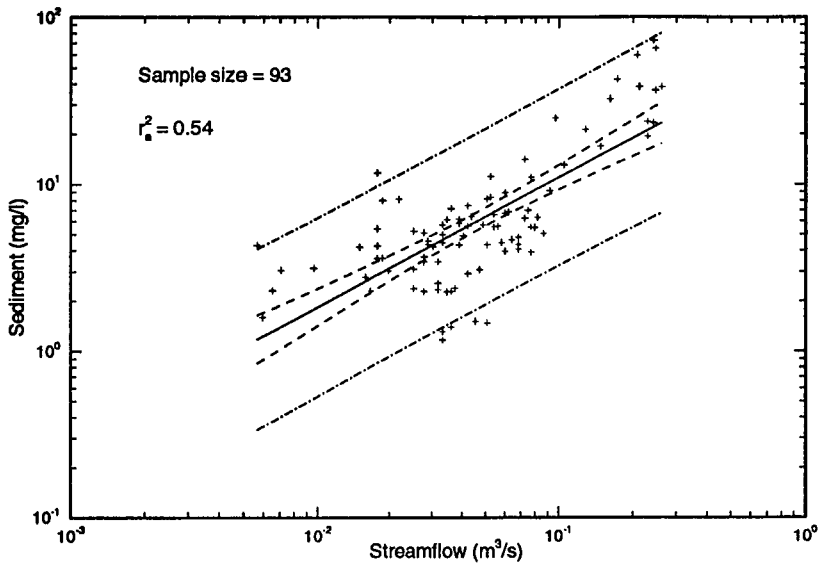


Figure C19. SRC and 95% confidence and prediction intervals for rising stage of event 1 on Watershed 1

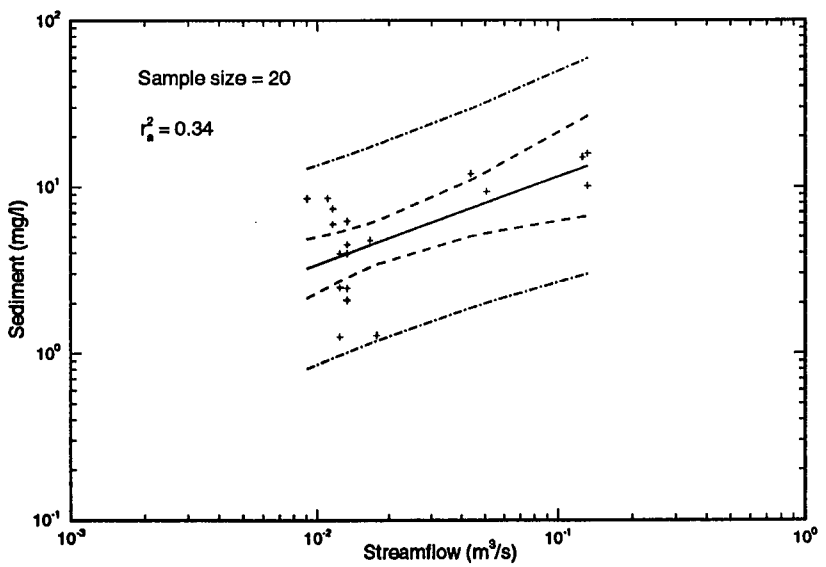


Figure C20. SRC and 95% confidence and prediction intervals for rising stage of event 2 on Watersed 1

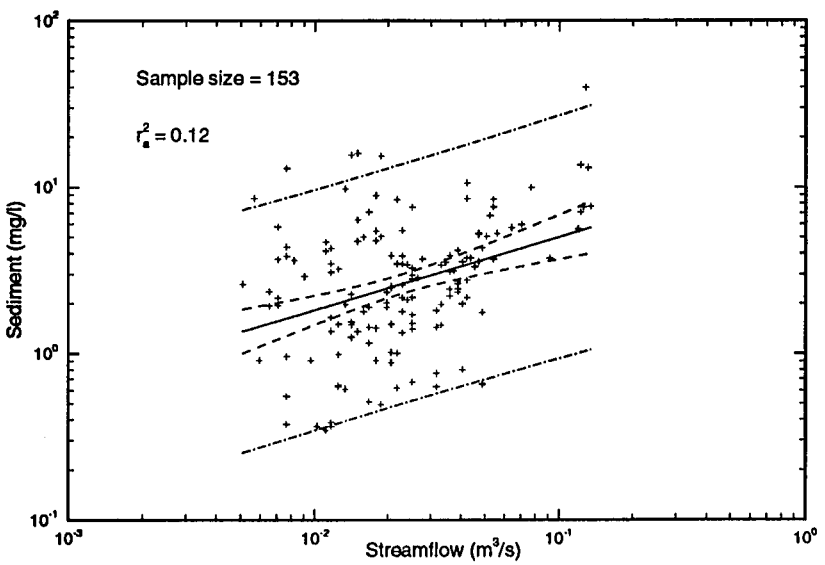


Figure C21. SRC and 95% confidence and prediction intervals for rising stage of event 1 on Watershed 2

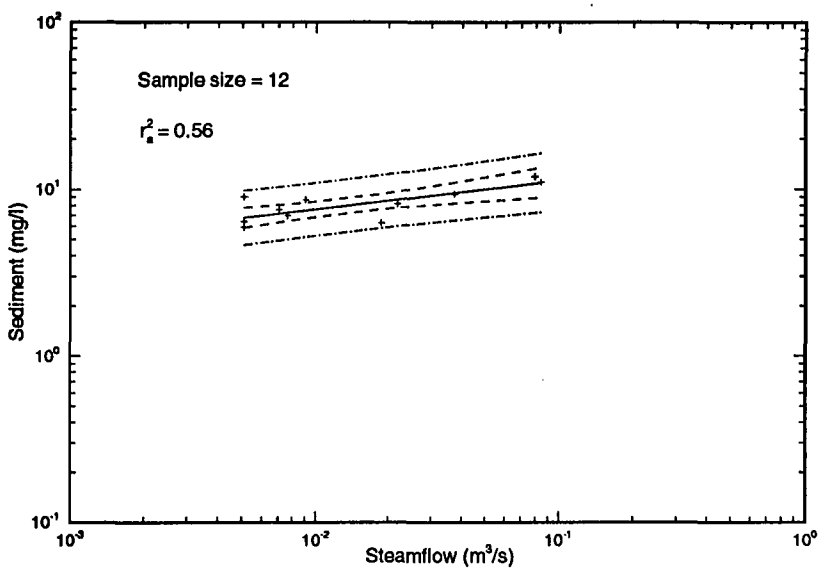


Figure C22. SRC and 95% confidence and prediction intervals for rising stage of event 2 on Watershed 2

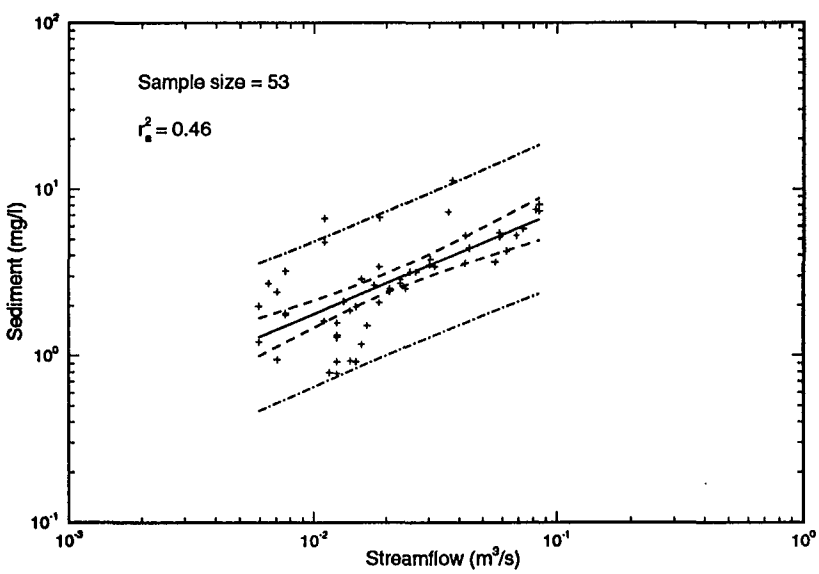


Figure C23. SRC and 95% confidence and prediction intervals for falling stage of event 2 on Watershed 2

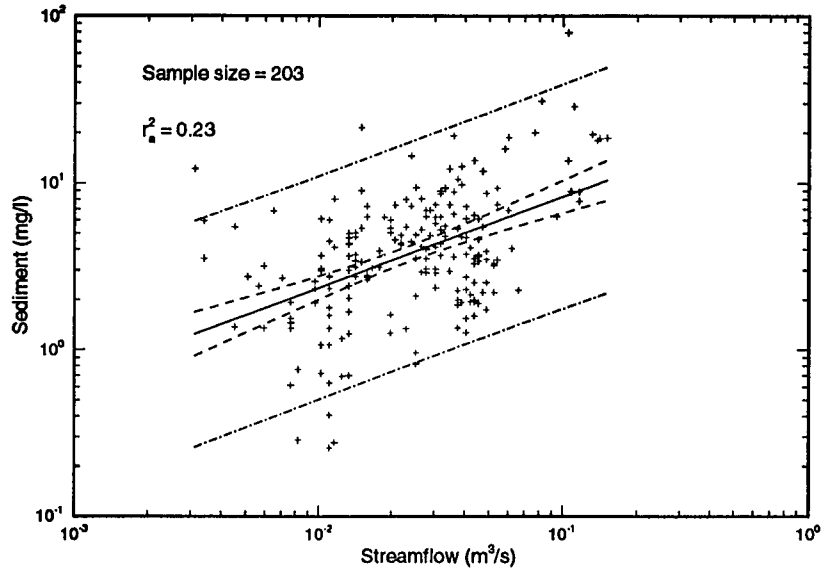


Figure C24. SRC and 95% confidence and prediction intervals for rising stage of event 1 on Watershed 3

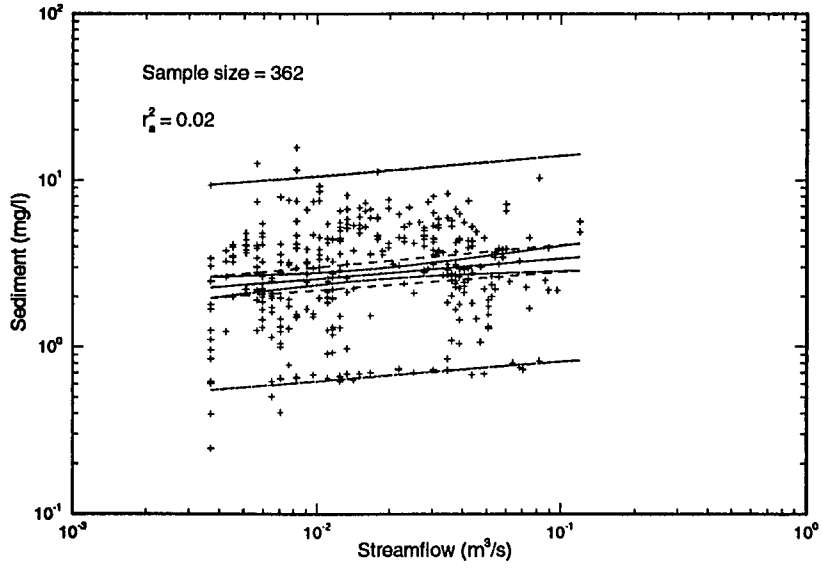


Figure C25. SRC and 95% confidence and prediction intervals for falling stage of event 1 on Watershed 3

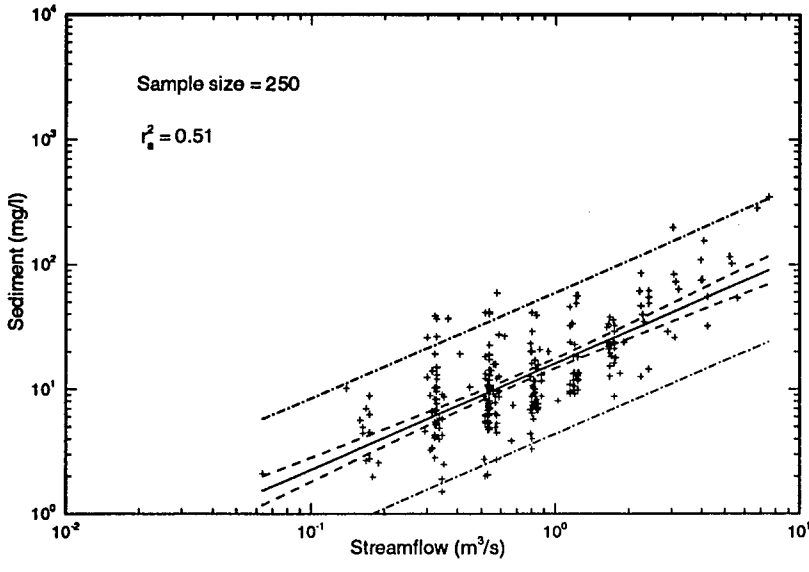


Figure C26. SRC and 95% confidence and prediction intervals for rising stage of event 1 on Watershed 8

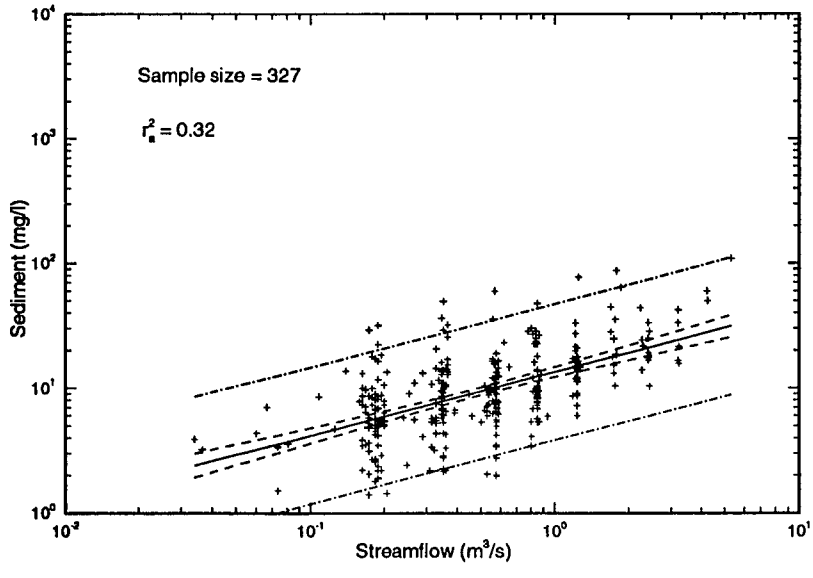


Figure C27. SRC and 95% confidence and prediction intervals for falling stage of event 1 on Watershed 8

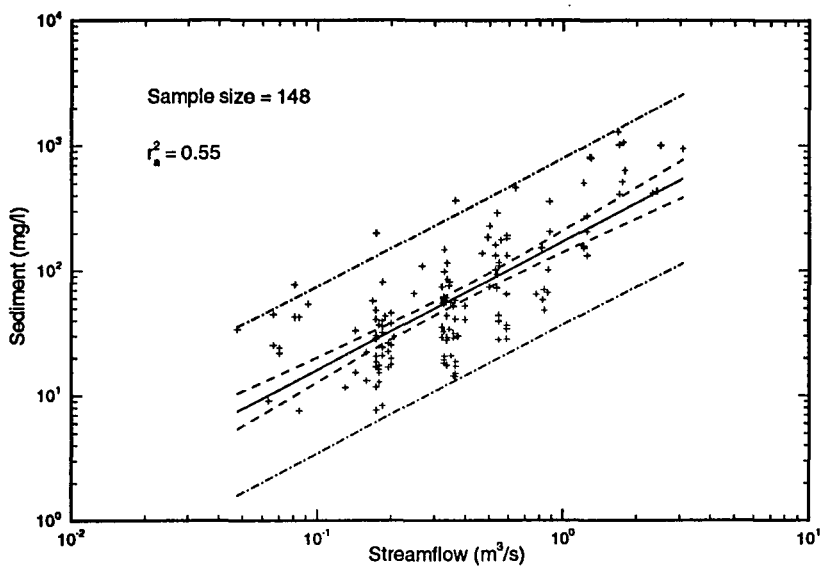


Figure C28. SRC & 95% confidence and prediction intervals for rising stage of event 1 on Watershed 12

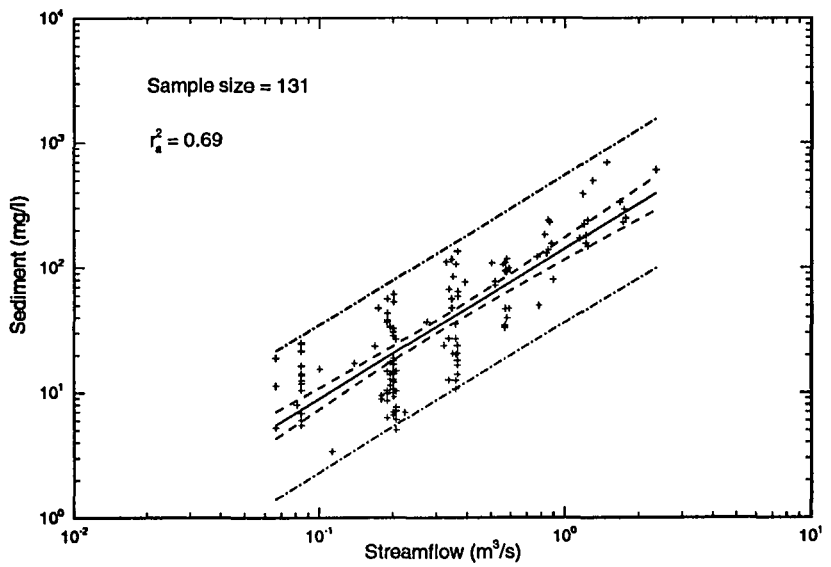


Figure C29. SRC and 95% confidence & prediction intervals for falling stage of event 1 on Watershed 12

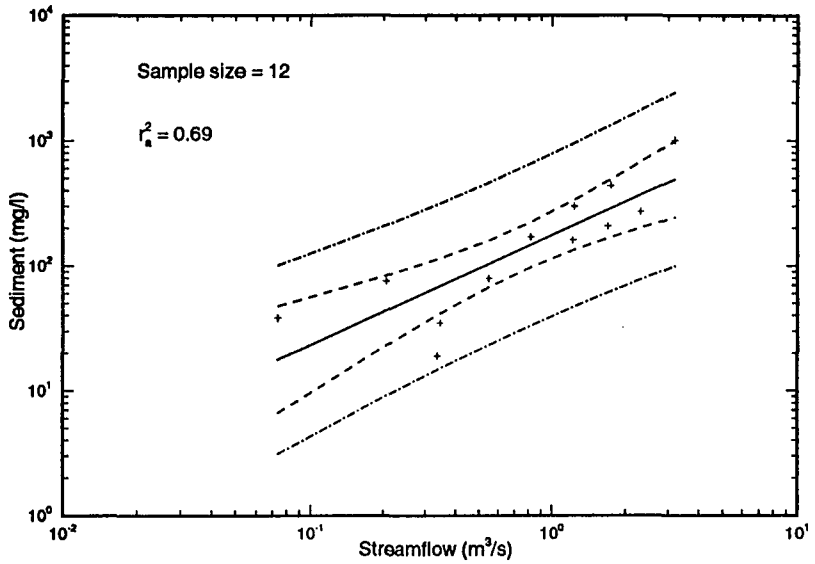


Figure C30. SRC and 95% confidence and prediction intervals for rising stage of event 3 on Watershed 12

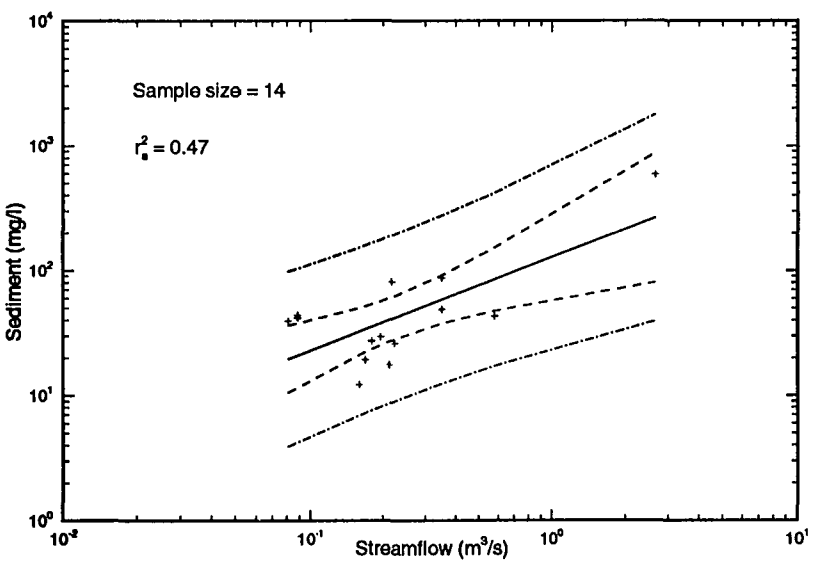


Figure C31. SRC and 95% confidence and prediction intervals for falling stage of event 3 on Watershed 12

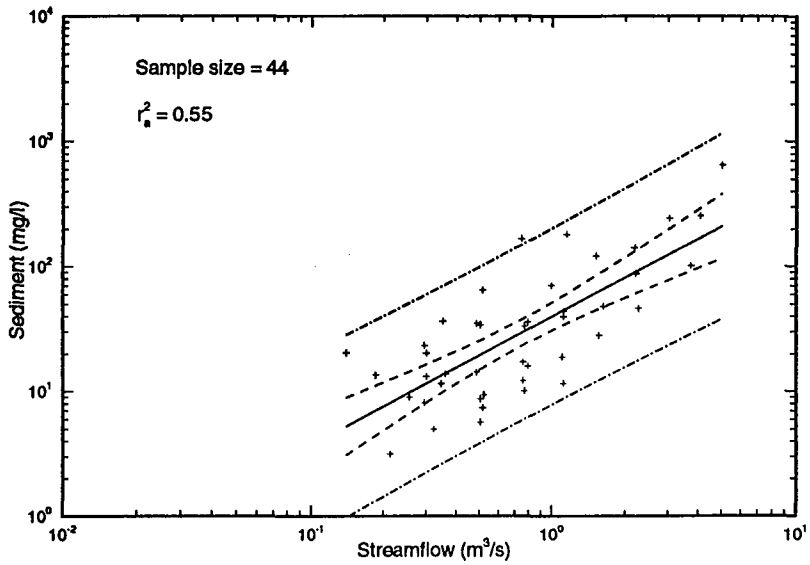


Figure C32. SRC and 95% confidence and prediction intervals for rising stage of event 1 on Watershed 13

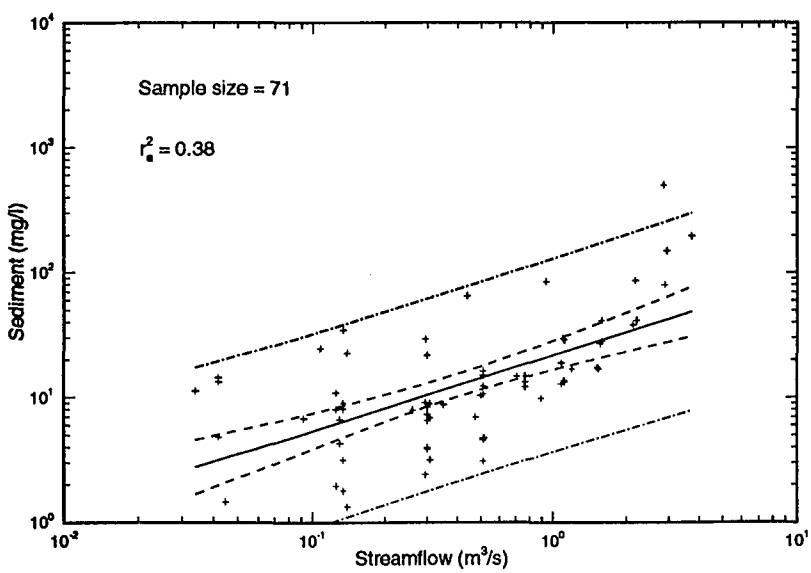


Figure C33.SRC and 95% confidence and prediction intervals for falling stage of event 1 on Watershed 13

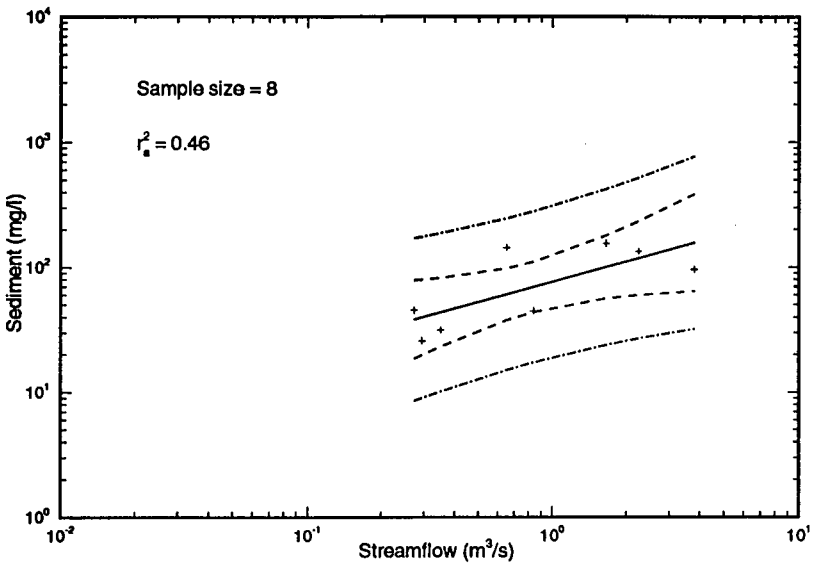


Figure C34. SRC and 95% confidence and prediction intrevals for rising stage of event 3 on Watershed 13

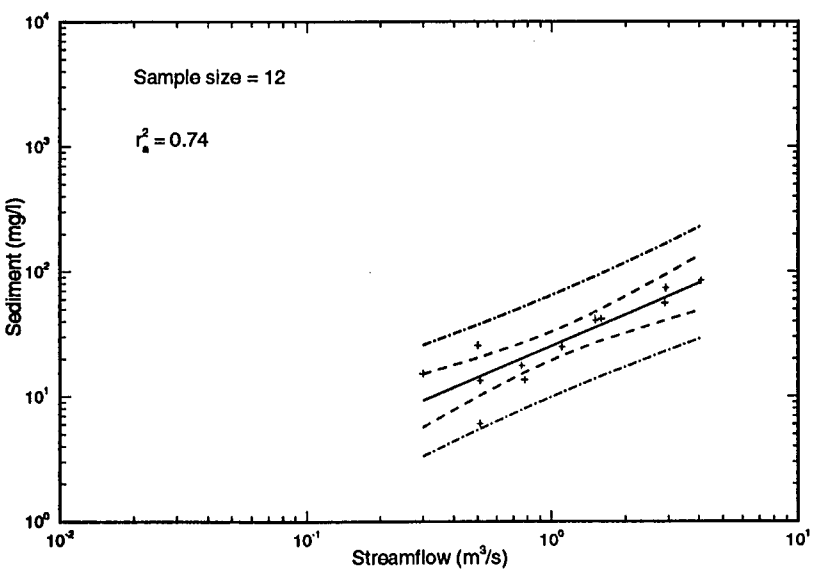


Figure C35. SRC and 95% confidence and prediction intervals for falling stage of event 3 on Watershed 13

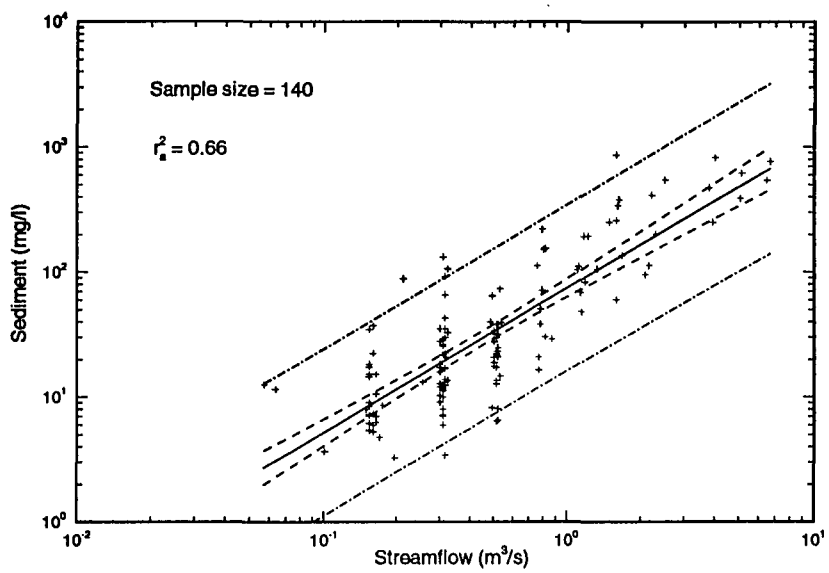


Figure C36. SRC and 95% confidence and prediction intervals for rising stage of event 1 on Watershed 14

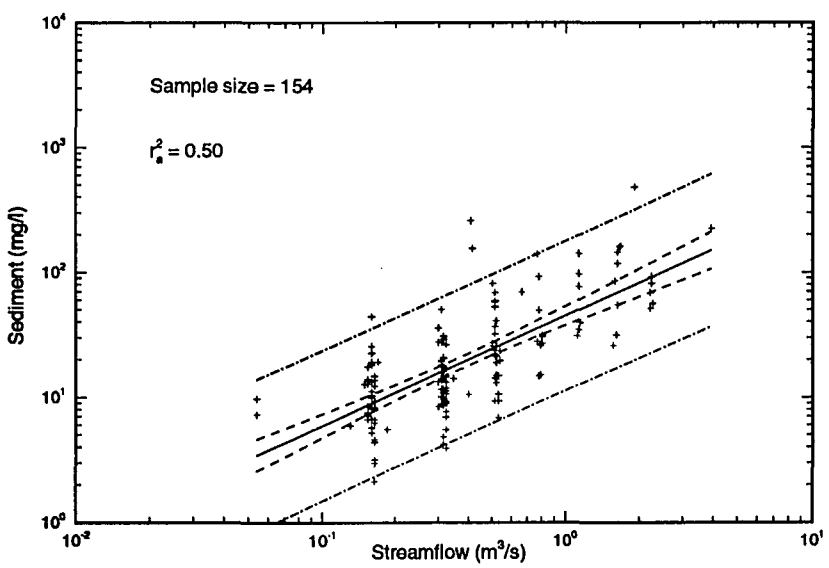


Figure C37. SRC and 95% confidence and prediction intervals for falling stage of event 1 on Watershed 14

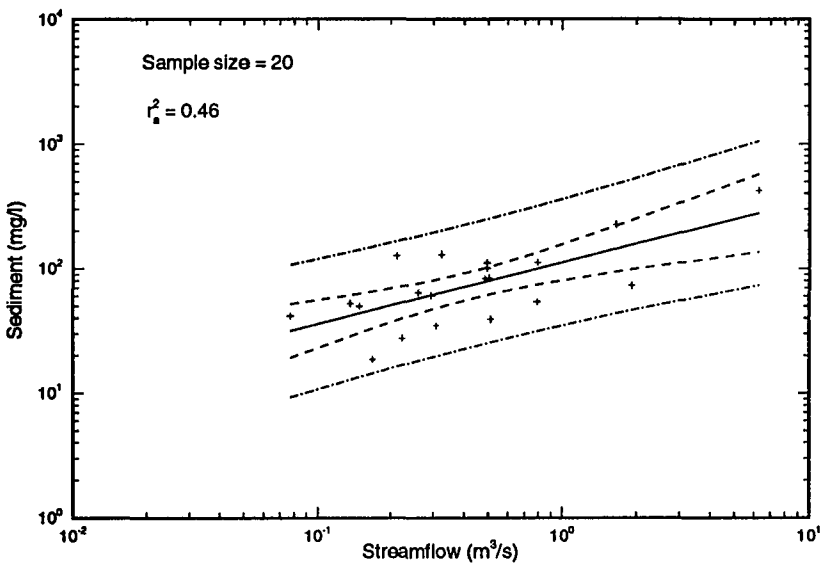


Figure C38. SRC and 95% confidence and prediction intervals for rising stage of event 3 on Watershed 14

APPENDIX D

CORRECTION FACTOR (*d*) IN THE CORRECTED LINEAR MODEL

Table D. Correction factor (d) in the corrected linear model

				Linear Model				Retransformed Linear Model			
Ws	Event Type	Stg	n	SSE	MSE	Skew	Nm	SSE	SE	Mean E (%)	Mean Residual
8	-	-	854	76.08	0.0893	0.46	n	327539	19.61	24	3.8
	1	-	828	72.27	0.0875	0.45	n	314811	19.52	24	3.7
		R	250	20.34	0.0820			187982	27.53	22	5.5
		F	327	24.78	0.0762			39532	11.03	21	2.5
12	-	-	353	39.59	0.1128	0.25	y	5569457	125.97	32	30.5
	1	-	326	36.27	0.1119	0.24	y	5094463	125.39	32	29.7
		R	148	16.27	0.1114			4188563	169.38	30	44.6
		F	131	11.18	0.0867			543590	64.91	25	16.0
	3	-	26	1.88	0.0783			440890	135.54	21	34.6
		R	12	0.78	0.0780			332649	182.39	20	44.6
		F	14	1.05	0.0875			117183	98.82	21	23.6
13	-	-	204	31.89	0.1579	0.37	y	761632	61.40	43	13.8
	1	-	179	27.07	0.1529	0.4	n	735005	64.44	41	13.7
14	-	-	473	63.73	0.1353	0.33	n	2526666	73.24	39	16.3
	1	-	432	53.99	0.1256	0.33	y	2415064	74.94	36	16.0

Nm = Normality of residuals

Table D. Correction factor (d) in the corrected linear model - continued

			d		Retransformed Corrected Linear Model							
					1				2			
Ws	Event Type	Stg	1	2	SSE	SE	Mean E (%)	Mean Residual	SSE	SE	Mean E (%)	Mean Residual
8	-	-	1.27	1.30	296805	19	57	1.0	294454	19	61	
	1	-	1.26	1.29	285225	19	56	1.0	282838	19	59	
		R	1.24	1.27								
		F	1.22	1.24								
12	-	-	1.35	1.37	4293199	111	78	6.1	4249859	110	81	4.8
	1	-	1.35	1.36	3965203	111	78	6.8	3944467	110	79	6.1
		R	1.34	1.36	3231003	149	74	15.1	3191463	148	76	13.4
		F	1.26	1.24	420805	57	58	1.0	425283	57	55	2.1
	3	-	1.23	1.19	313774	114	48	7.6	330301	117	44	12.3
		R	1.23	1.17	250689	158	48	0.6	265237	163	41	12.1
		F	1.26	1.21	79222	81	52	8.9	85518	84	46	11.7
13	-	-	1.52	1.55	642812	56	118	3.7	638188	56	122	3.2
	1	-	1.50	1.53	627658	60	112	5.6	622539	59	116	5.1
14	-	-	1.43	1.47	1939436	64	98	3.4	1953153	64	104	2.2
	1	-	1.39	1.43	1916979	67	88	4.9	1885509	66	94	3.8

Correction factor:

1. $d = 10^{1.15\sigma^2}$

2. $d = \frac{1}{n}\sum 10^{\varepsilon_i}$, nonparametric (Duan, 1983)

LITERATURE CITED

Anderson, H. W., M. D. Hoover, and K. G. Reinhart. 1976. Forest and water: effects of forest management on floods, sedimentation, and water supply. General Technical Report PSW-18. USDA Forest Service, Pacific Southwest Forest and Range Experimental Station, Berkeley, California, pp. 115.

Baird, R. W. 1964. Sediment yield from Blackland watersheds. Transactions of the ASAE 7(4): 454-456.

Baker, M. B., Jr. 1975. Modeling management of ponderosa pine forest resources. Watershed Management. Proceedings of A Symposium Conducted by the Committee on Watershed Management of the Irrigation and Drainage Division of ASCE Utah Section. ASCE, New York, New York, pp. 478-493.

Baker, M. B., Jr. 1982. Hydrologic regimes of forested area in the Beaver Creek watershed. General Technical Report RM-90. USDA Forest Service, Rocky Mountain Forest and Range Experimental Station, Fort Collins, Colorado, pp. 8.

Baker, M. B., Jr. 1984. Changes in streamflow in a herbicide-treated pinyon-juniper watershed in Arizona. Water Resources Research 20(11): 1639-1642.

Baker, M. B., Jr. 1986a. Effects of ponderosa pine treatments on water yield in Arizona. Water Resources Research 22(1): 67-73.

Baker, M. B., Jr. 1986b. A supercritical flume for measuring sediment-laden streamflow. Water Resources Bulletin 22(5): 847-851.

Baker, M. B., Jr. 1987. The diversity in streamflow response from upland basins in Arizona. Management of Subalpine Forests: Building on 50 Years of Research. General Technical Report RM-149. USDA Forest Service, Rocky Mountain Forest and Range Experimental Station, Fort Collins, Colorado, pp. 210-215

Barr, G. W. 1956. Recovering Rainfall. Department of Agricultural Economics, University of Arizona, Tucson, Arizona, pp. 218.

Bennett, J. P. 1974. Concepts of mathmatical modeling of sediment yield. Water Resources Research 10(3): 485-492.

Beschta, R. L. 1978. Long-term patterns of sediment production following road construction and logging in the Oregon coast range. Water Resources Research 10(3): 1011-1016.

Beschta, R. L. 1987. Conceptual of sediment transport in streams. Sediment Transport in Gravel-bed Rivers (C. R. Thorne, J. C. Bathust, and R. D. Hey, eds.), Chapter 13. John Wiley and Sons Ltd. Chichester, pp. 387-419.

Brown, H. E. 1971. Evaluating watershed management alternatives. Journal of the Irrigation and Drainage Division, Proceedings of ASCE 97(IR1): 93-108.

Brown, H. E., Baker, M. B., Jr., J. J. Roger, W. P. Clary, J. L. Kovner, F. R. Larson, C. C. Avery, and R. E. Campbell. 1974. Opportunities for Increasing Water Yields and Other Multiple Use Values on Ponderosa Pine Forest Lands. Research Paper RM-129. USDA Forest Service, Rocky Mountain Forest and Range Experimental Station, Fort Collins, Colorado, pp. 36.

Campbell, F. B., and H. A. Bauder. 1940. A rating-curve method for determining silt-discharge of streams. Transactions of the American Geographic Union 21: 603-607.

Clary, W. P. 1975. Multiple use effects of manipulating pinyon-juniper. Watershed Management. Proceedings of A Symposium conducted by the Committee on Watershed Management of the Irrigation and Drainage Division of ASCE Utah Section. ASCE, New York, New York, pp. 469-477.

Clary, W. P., M. B. Baker, Jr., P. F. O'Connell, T. N. Johnsen, Jr., and R. E. Campbell. 1974. Effects of Pinyon-Juniper Removal on Natural Resource Products and Uses in Arizona. Research Paper RM-128. USDA Forest Service Rocky Mountain Forest and Range Experimental Station, Fort Collins, Colorado, pp. 28.

Cohn, T. A., L. L. Delong, E. J. Gilroy, R. M. Hirsh, and D. K. Wells. 1989. Estimating constituent loads. Water Resources Research 25(5): 937-942.

Colby, B. R. 1956. Fluvial Sediments. USGS Bull. 1181-A.

Copeland, O. L. 1965. Land use and ecological factors in relation to sediment yields. In: USDA Miscellaneous Publication 970, Proceedings of the Federal Inter-Agency Sedimentation Conference 1963, pp. 72-84.

Crawford, C. G. 1991. Estimation of suspended-sediment rating curves and mean suspended sediment loads. Journal of Hydrology 129: 331-348.

Davis, D. 1994. Personal communication.

Daniel, C., and F. S. Wood. 1980. Fitting Equations to Data. Wiley, New York, New York, pp. 458.

Duan, N. 1983. Smearing estimate -- a nonparametric retransformation method. Journal of the American Statistical Association 78: 605-610.

Elsheikh, S., A. Kaikai, and K. Andah. 1991. Intensive sediment transport from the upper Nile Basin and water resources management in Sudan. Hydrology for the Water Management of Large River Basins. Proceedings of the Vienna Symposium, August 1991. ASHS Publication no. 201, pp. 291-300.

Fenn, C. R., A. M. Gurnell, and I. R. Beecroft. 1985. An evaluation of the use of suspended sediment rating curves for the prediction of suspended sediment concentration in a preglacial stream. Geografiska Annaler 67A(1-2): 71-82.

Ferguson, R. I. 1986. River loads underestimated by rating curves. Water Resources Research 22(1): 74-76.

Feth, J. H. and J. D. Hem. 1963. Reconnaissance of headwater springs in the Gila River Basin, Arizona. Water-Supply Paper 1619-H, USGS, Washington, D.C., pp. 54.

Ffolliott, P. F., W. P. Clary, and J. R. Davis. 1968. Some characteristics of the forest floor under ponderosa pine in Arizona. Research Note RM-127. USDA Forest Service, Rocky Mountain Forest and Range Experimental Station, Fort Collins, Colorado, pp. 4.

Ffolliott, P. F., and G. J. Gottfried. 1991. Natural tree regeneration after clearcutting in Arizona's ponderosa pine forests: Two long-term case studies. Research Note RM-507. USDA Forest Service, Rocky Mountain Forest and Range Experimental Station, Fort Collins, Colorado, pp. 6.

Ffolliott, P. F., and E. A. Hansen. 1968. Observations of snowpack accumulation, melt, and runoff on a small Arizona watershed. Research Note RM-124. USDA Forest Service, Rocky Mountain Forest and Range Experimental Station, Fort Collins, Colorado, pp. 7.

Ffolliott, P. F., P. R. Krausman, and N. S. Smith. 1991. Small game habitat. Managing Wildlife in the Southwest .

Ffolliott, P. F., and D. B. Thorud. 1975. Water Yield Improvement by Vegetation Management, Focus on Arizona. U.S. Department of Commerce, National Technical Information Service, Virginia.

Ffolliott, P. F., and D. P. Worley. 1973. Forest stocking equations: their development and application. Research Paper RM-102. USDA Forest Service Rocky Mountain Forest and Range Experimental Station, Fort Collins, Colorado, pp. 8.

Flaxman, E. M. 1972. The use of suspended-sediment load measurements and equations for evaluation of sediment yield in the west. In: Present and Prospective Technology for Predicting Sediment Yield and Sources, Proceedings of the Sediment-Yield Workshop. USDA Sedimentation Lab, Oxford, Mississippi, pp. 46-56.

Gilroy, E. L., W. H. Kirby, T. A. Cohn, and G. D. Glysson. 1990. "Uncertainty in suspended sediment transport curves" (McBean, E. A., and S. Al-Nassri, 1988) Discussion. Journal of Hydraulic Engineering 116(1): 143-145.

Glymph, L. M. 1972. Evolving emphasis in sediment-yield predictions. In: Present and Prospective Technology for Predicting Sediment Yield and Sources, Proceedings of the Sediment-Yield Workshop. USDA Sedimentation Lab, Oxford, Mississippi, pp. 1-4.

Glysson, G. D. 1987. Sediment Transport Curves. USGS Open-File Report 87-218, pp. 47.

Graf, W. H. 1971. Hydraulics of Sediment Transport. McGraw-Hill, New York, New York, pp. 513.

Grenny, W. J., and E. Heyse. 1985. Suspended sediment--river flow analysis. Journal of Environmental Engineering 111(6): 790-803.

Gurnell, A. M., and C. R. Fenn. 1984. Box-Jenkins function models applied to suspended sediment concentration-discharge relationship in a proglacial stream. Arctic and Alpine Research 16(1): 93-106.

Haddad, M. S. 1990. The Effects of Watershed Treatments on the Relationship between Runoff Peak and Volume for the Beaver Creek Watershed, Arizona. MS thesis, University of Arizona, Tucson, Arizona.

Haan, C. T. 1977. Statistical Methods in Hydrology. Iowa State University Press, Ames, Iowa, pp. 378.

Hansen, E. A. 1966. Suspended sediment concentration as related to watershed variables in central Arizona. Hydraulics Division Conference. ASCE, Madison, Wisconsin. Mimeo paper, pp. 14.

Heidmann, L. J., F. R. Larson, and W. J. Rietveld. 1977. Evaluation of ponderosa pine reforestation techniques in central Arizona. Research Paper RM-190. USDA Forest Service, Rocky Mountain Forest and Range Experimental Station, Fort Collins, Colorado, pp. 10.

Jansson, M. 1985. A comparison of detransformed logarithmic regressions and power function regressions. Geografiska Annaler 67A(1-2): 61-70.

Jeton, A. E. 1990. Vegetation Management and Water Yield in A Southwestern Ponderosa Pine Watershed: An Evaluation of Three Hydrological Simulation Models. MS thesis. University of Arizona, pp. 181.

Kmenta, J. 1986. Elements of Econometrics. MacMillan Publishing Co., New York, New York, pp. 786.

Koch, R. W. and G. M. Smillie. 1986. Bias in hydrologic prediction using log-transformed regression models. Water Resources Bulletin 22(6): 717-723.

Langbein, W. B., and S. A. Schumm. 1958. Yield of sediment in relation to mean annual precipitation. Transactions of American Geographic Union 39(6): 1076-1084.

Livesey, R. H. 1972. Corps of Engineers methods for predicting sediment yields. In: Present and Prospective Technology for Predicting Sediment Yield and Sources, Proceedings of the Sediment-Yield Workshop. USDA Sedimentation Lab, Oxford, Mississippi, pp. 16-32.

Lopes, V.L. and P.F. Ffolliott. 1992. Modeling sediment processes on small watersheds: A conceptual framework, I. Broad shallow flow processes. International Journal of Sediment Research 7(3): 21-44, Beijing, P.R. China.

Lopes, V. L., and P. F. Ffolliott. 1993. Sediment rating curves for a clearcut ponderosa pine watershed in northern Arizona. Water Resources Bulletin 29(13): 369-82.

McBean, E. A. and S. Al-Nassri. 1988. Uncertainty in suspended sediment transport curves. Journal of Hydraulic Engineering 114(1): 63-73.

Meyer, L. D. 1972. Soil erosion by water on upland areas. In: River Mechanics (H. W. Shen, ed.). Chapter 27. Water Resources Publication, Littleton, Colorado.

Miller, C. R. 1951. Analysis of Flow-Duration, Sediment-Rating Curve Method of Computing Sediment Yield. Bureau of Reclamation, U.S. Department of Interior, Denver, Colorado, pp. 55.

Miller, R. G., Jr. 1981. Simultaneous Statistical Inference (2nd ed.). Springer-Verlag, New York, New York, pp. 190.

Neter, J., W. Wasserman, and M. H. Kutner. 1985. Applied Linear Statistical Models: Regression, Analysis of Variance, and Experimental Designs (2nd ed.). Richard D. Irwin Inc., Homewood, Illinois, pp. 1127.

Norusis, M. J. 1985. SPSSX-Advanced Statistics Guide. McGraw-Hill. New York, New York, pp. 505.

Parker, R. S. and B. T. Troutman. 1989. Frequency distribution for suspended loads. Water Resources Research 25(7): 1567-1574.

Patric, J. H., J. O. Evans, and J. D. Helvey. 1984. Summary of sediment yield data from forested land in the United States. Journal of Forestry: 101-104.

Piest, R. F. 1963. Longterm sediment yields from small watersheds. IAHS Publication No. 65, pp. 121-140.

Porterfield, G. 1972. Computation of Fluvial-Sediment Discharge. Techniques of Water-Resource Investigations of the United States Geological Survey. Book 3, Chapter C3. United States Government Printing Office, Washington, D. C., pp. 66.

Renard, K. G. 1969. Sediment rating curves in ephemeral streams. Transactions of the ASAE 12(1): 80-85.

Ryan, T. P. 1990. Linear regression. In: Handbook of Statistical Methods for Engineers and Scientists. (H. M. Wadsworth, ed.). McGraw-Hill, Inc., New York, New York, pp. 13.1-13.37.

Shen, H. W., and R. M. Li 1976. Watershed sediment yield. In: Stochastic Approach to Water Resources. Volume II, Chapter 21. Colorado State University, Fort Collins, Colorado, pp. 21.1-21.68.

Springfield, H. W. 1976. Characteristics and management of southwestern pinyon-juniper ranges: the status of our knowledge. Research Paper RM-160. USDA Forest Service, Rocky Mountain Forest and Range Experimental Station, Fort Collins, Colorado, pp. 32.

Sullivan, K 1985. Long-term patterns of water quality in a managed watershed in Oregon: 1. Suspended sediment. Water Resources Bulletin 21(6): 977-987.

Thomas, R. B. 1988. Monitoring baseline suspended sediment in forested basins: the effect of sampling on suspended sediment rating curves. Hydrological Sciences -- Journal 33(5): 499-514.

United States Army Corps of Engineers. 1961. Reservoir Sedimentation Investigation Program, Manuals, EM 1110-2-4000.

US Department of Commerce. 1967. Rainfall frequency atlas of Arizona for durations of 6-24 hours and return periods from 2 to 100 years. Technical Report, U.S. Department of Commerce, Washington, D. C.

USGS. 1972. Computation of fluvial-sediment discharge. Techniques of Water-Resources Investigations of the United States Geological Survey, Book 3 Chapter C3, pp. 66.

USGS. 1977. Sediment. In: National Handbook of Recommended Methods for Water-Data Acquisition. Reston, Virginia, pp. 3.1-3.100.

Vanoni, V. A. (ed.). 1975. Sedimentation Engineering. ASCE Manuals and Reports on Engineering Practice No. 54, New York, New York, pp. 745.

Walling, D. E. 1977. Assessing the accuracy of suspended sediment rating curves for a small basin. Water Resources Research 13(3): 531-538.

Walling, D. E., and A. Teed. 1971. A simple pumping sampler for research into suspended sediment transport in small catchments. Journal of Hydrology 13: 325-337.

Walling, D. E., and B. W. Webb. 1987. Suspended load in gravel-bed rivers: UK experience. Sediment Transport in Gravel-bed Rivers (C. R. Thorne, J. C. Bathust, and R. D. Hey, eds.), Chapter 22. John Wiley and Sons Ltd. Chichester, England, pp. 691-732.

Ward, T. J., and M. B. Baker. 1984. Sediment from managed pine watershed in northern central Arizona. In: Proceedings of the ASCE Irrigation and Drainage Specialty Conference, Flagstaff, Arizona, pp. 552-558.

Weber, J, 1994. Personal communication.

Wigdor, Y. 1994. Applicability of Selected Sediment Transport Equations to Pinyon-juniper Woodlands. MS thesis. University of Arizona, pp. 109.

Williams, G. P. 1989. Sediment concentration versus water discharge during hydrologic events in rivers. Journal of Hydrology 111: 89-106.

Williams, J. A., and T. C. Anderson, Jr. 1967. Soil Survey, Beaver Creek Area, Arizona. Technical report. USDA Forest Service and Soil Conservation Service, and Arizona Agricultural Experimental Station. U.S. Government Printing Office, Washington, D. C., pp. 75.

Wonnacott, T. H., and R. J. Wonnacott. 1981. Regression: A Second Course in Statistics. John Wiley and Sons. New York, New York, pp. 556.

Yang, C. T. 1973. Incipient motion and sediment transport. Journal of the Hydraulics Division (ASCE) 99 (HY10): 1679-1704.

Yang, C. T. 1988. Sediment transport and unit stream power. Civil Engineering Practice, Vol. 5, Chapter 8, Technomic Publishing Co., pp. 265-289.